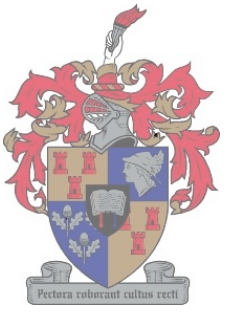
NURSERY RESULTS ON GENETIC VARIATION, VEGETATIVE PROPAGATION AND OTHER GROWTH FACTORS OF IMPORTANCE FOR DOMESTICATION OF *PTEROCARPUS ANGOLENSIS* DC.

BY



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Thesis submitted in partial fulfilment of the requirements for a Master of Science degree in Forestry at the University of stellenbosch

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Declaration

I, the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety, or in part, been submitted at any university for a degree.

Date: February, 1998.

Opsomming

Pterocarpus angolensis is 'n belangrike inheemse houtsoort wat in die warm en somer reënvalgebiede van suider- en sentraal Afrika voorkom. Dit behoort tot die familie *Fabaceae*, 'n sub-familie van *Leguminosae*. Fenotipies superieure bome word ontgin deur bestaans- en kommersiële houtgebruikersindustrieë. Plaaslike inwoners in die gebiede waar *P. angolensis* groei gebruik dit vir medisinale, boot en stamper-en-vysel vervaardiging. Oorbenutting van die spesie vind teen 'n hoë tempo plaas, maar daar word nie baie navorsing in verband met die boskultuur, veredeling en domestikasie van die spesie gedoen nie. Sommige van die probleme wat geassosieer word met die spesie is: stadige tempo van natuurlike regenerasie, probleme om steggies te laat wortel en die behandeling van saad voor ontkieming om dormansie te breek.

Vier herkomste van Chimanimani (Zimbabwe), Masese, Mufumbwe en Solweni (Zambië) en elf families van die Masese herkoms is ondersoek vir bestaande variasies in terme van saailing groeitempos. Die eksperimente is uitgevoer in die kwekery van die Fakulteit van Bosbou van die Universiteit van Stellenbosch. Die doelstellings van die studie was om (i) die reaksie van vier herkomste op grondsterilisasie en -inokulasie, (ii) bestaande saailing groeivariasies en (iii) loot- en wortelvorming van steggies te bestudeer.

Daar was beduidende verskille in saailing ontkiemingstempos, gemiddelde saailinghoogtes, wortelkraagdeursnee en totale bo- en ondergrond biomassas tussen herkomste, families, grondsterilisasie en -inokulasie behandelinge. Die gemiddelde hoogtes van die Mfumbwe herkoms was beduidend hoër vanaf die tyd van plant tot 217 dae van saailinggroei. Die Chimanimani herkoms het hoër bo- en ondergrond biomassa, maar het die laagste gemiddelde saailinghoogte.

Variasies in groei is waargeneem in die elf families van een herkoms. Die inokulasie van die grond, anders as sterilisasie, was meer voordelig vir saailinggroei. Byna al die steggies het maklik lote geproduseer, maar daar was geen wortelontwikkeling. Die lote het nie lank oorleef nie. Slegs in die deursnee klas 3 – 4.9 cm het lote teen dag 104 van die eksperiment nog oorleef. Dit is noodsaaklik dat navorsingswerk op *P. angolensis* voortgesit moet word, want dit word deur uitsterwing bedreig en die industrieë wat daarop staatmaak sal dan swaarkry.

Summary

Pterocarpus angolensis is an important indigenous timber tree species occurring in warm and summer rainfall areas of southern and central Africa. It belongs to the family Fabaceae, a subfamily of Leguminosae. Phenotypically superior trees are exploited by subsistence and commercial timber using industries. Local people found in areas where *P. angolensis* grows, use it for medicinal and boat, mortar and pestle manufacture. Exploitation of the species is at a high rate, however, not much research on its silviculture, tree improvement and domestication has been done. Some problems associated with the species are: slow natural regeneration, difficulty in rooting cuttings and requirement of seed treatment prior to germinating it in order to break the dormancy.

Four Provenances from Chimanimani (Zimbabwe), Masese, Mufumbwe and Solwezi (Zambia) and eleven families from Masese provenance were investigated for their existing variations in terms of seedling growth rates. The trials were conducted at the Faculty of Forestry nursery, University of Stellenbosch. The objectives were to study (i) the response of the four provenances to soil sterilisation and inoculation (ii) existing seedling growth variations (iii) the shooting and rooting ability of cuttings.

There were significant differences in seed germination rates, mean seedling height, root collar diameter and total above and below ground biomass between provenances, families, soil sterilisation and inoculation treatments. Mufumbwe provenance had a significantly higher mean height from time of planting to 217 days of seedling growth. Chimanimani provenance had higher above and below ground biomass than other provenances but had the lowest seedling mean height.

Seedling growth variations were observed in the eleven families from one provenance. Soil inoculation, unlike sterilisation, was found to be more beneficial to seedling growth. Almost all cuttings produced shoots easily but with no root development. Shoots were not maintained for a long period. Only diameter class 3 - 4.9 cm had surviving shoots by day 104 of the experiment. There is need to continue with research work on *P. angolensis* otherwise it is under extinction threat and industries relying on the species would suffer.

Acknowledgements

My sincere thanks and appreciation to my supervisor, Professor Gerrit Van Wyk, and my Co - supervisor Dr. J. M. Theron, for their constructive input and motivational comments which helped me through difficult times.

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I thank the National Council for Scientific Research, Kitwe, Zambia for helping me with the glass house where the vegetative propagation trials on *P. angolensis* were conducted. Many thanks also go to the staff of Forest Research Division, Kitwe, especially Mr. Godfrey K. Sichinga for looking after my experiment while I was at Stellenbosch studying.

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1. Introduction

The genus *Pterocarpus* is pantropical (Munyanziza, 1994). *Pterocarpus angolensis* DC. is a widely distributed timber tree species found in eastern (Tanzania), central (Democratic Republic of Congo) and southern Africa (Angola, Malawi, Mozambique, Namibia, South Africa, Zambia and Zimbabwe) (Palgrave, 1988 and Storrs, 1995).

The species can grow into a tall tree on good sites and can be found as a shrub, for example in Angola. According to Vermeulen (1990), under natural conditions the species takes approximately 90 years to mature.

P. angolensis has many uses both at subsistence and commercial level. Almost all parts of the tree are utilised for medicinal purposes by the indigenous people in the areas where it grows. Commercially, it is used in the carpentry industries. In Zambia, many volumes of timber are exploited each year for export to neighbouring countries such as Botswana and South Africa. *P. angolensis* timber is exploited by subsistence and commercial companies such as Lualaba Timbers, Wood Processing Industries, Furniture Manufacturing Co-operation of Zambia and Zambezi sawmills. In the Southern African Development Community (SADC) region, *P. angolensis* timber prices are quite competitive when compared with other valued timbers (Table 1.1).

P. angolensis timber is in high demand compared with teak, mahogany and other miombo woodland timber species. It is among the most preferred and wanted hardwoods of the miombo woodlands in Africa (Palgrave, 1988 and Munyanziza, 1994) yet the genus *Pterocarpus* appears to have many silvicultural problems which have received little attention. The demand for its timber and other products is far beyond what natural forests can supply. Meanwhile, there is lack of information on an alternative timber tree species (Munyanziza, 1994). *P. angolensis* has been cut to vulnerable levels (Wanyancha *et al.*, 1993) and it is also under serious genetic erosion since most of the phenotypically superior trees are always logged leaving behind only inferior ones.

Table 1.1 Price list of *P. angolensis* timber in comparison with other important timber tree species in the SADC region. All references were personal communication.

Name of country	*P. angolensis* price in US $ per m^3	other species	price in US $ per m^3	source
Angola	350 - 400	*Baikiaea plurijuga* *Entandrophragma*	200 250 - 300	Veloso (1997) Veloso (1997)
Zambia	700	Rosewood	750	FPPI* (1997)
Mozambique	300 - 320	*Milletia stuhlmannii* *Alfzelia quanzensis* *Encephalartos natalensis*	300 - 320 260 - 320 220	Lutze (1997) Lutze (1997) Lutze (1997)
South Africa	844 -1 220	*Tectona grandis* *Entandrophragma* Rosewood	6 700 1 000 1 000	Bovet (1997) Bovet (1997) Casteling (1997)
Zimbabwe	250 - 300	–	–	Mushove (1997)

** FPPI means Forest Products Processing Industries.*

There are several other problems associated with the species. The pod is indehiscent and covered with thorny bristles making fruit and seed collection, handling and extraction difficult, slow and expensive. Munyanziza (1994) reported seed extraction rates as low as 30 seeds per hour using the beating method. Seeds are further compounded with a marked dormancy problem making seed germination slow and irregular unless seeds are treated before sowing. Under natural conditions agents such as fires, temperature and animals, play a major role in breaking the dormancy. According to Van Daalen *et al.* (1992) and Munyanziza (1994), uncontrolled bush fires however, tend to damage most of the seeds.

P. angolensis seedlings have a tendency of dying back once a year during the harsh weather conditions (Boaler, 1966 and Nkaonja, 1982). The die-back is called the suffrutex stage. Under natural conditions, very few plants reach the sapling stage due to the suffrutex condition (Trapnell, 1959 and Vermeulen, 1990). No research results on the cause of seedling die-back are however available (Vermeulen, 1990).

Although *P. angolensis* is a valuable timber tree species, in Zambia, concerted efforts have not been made to study its phenology, seed biology and silviculture in detail. The ecology and survey of the species was last done by Palgrave (1956), White (1962), Lawton (1978) and Storrs (1982). Previous research work has not been very detailed and little has been done and published about the species.

No adequate knowledge on raising the species in artificial plantations is available. *P. angolensis* has virtually not been tried under artificial management. Its natural regeneration has been reported by Boaler (1966) to be poor and slow, hence frustrating the afforestation programme.

No known tree improvement, breeding programme, provenance and family trials of *P. angolensis* have been conducted or reported in Zambia. Yet, trees exhibit great variations in their characteristics such as height, diameter and biomass growth and timber quality. According to Falkenhagen (1978); Wright and Baylis (1993) these variations can only be identified through provenance and family trials. These variations could be of economic value to nations and could aid in domestication of *P. angolensis.*

Vegetative propagation using cuttings has been tried with no success. Meanwhile, gains from vegetative propagation could far exceed those from sexual breeding (Van Wyk, 1985).

The above highlighted problems, together with the popularity of the species for its timber and other minor products, could endanger its survival outside managed forests. Sustained timber production for industries depending on the species is also made difficult. According to Van Wyk (1994) changes and improvements in tree growth, quantity and quality can be brought about through breeding and parental control. Breeding work and domestication of *P. angolensis* can only take place after best seed and other propagule sources have been identified. Vegetative propagation, provenance and family trials, can provide the information required for such programmes.

The objectives of the study conducted at the Faculty of Forestry nursery, University of Stellenbosch, were therefore to carry out:

1) Provenance trials of four known seed origins of *P. angolensis* namely, Mufumbwe, Solwezi, Masese (Zambia) and Chimanimani (Zimbabwe).
2) Studies on the response of these different provenances to different soil treatments. Treatments were:
   a) soil inoculation with mycorrhizal fungi,
   b) soil sterilisation by steaming,
   c) no soil sterilisation and
   d) no soil inoculation.
3) a) Studies on the growth differences of 11 families of *P. angolensis* from Masese provenance growing under similar environment.
   b) Studies on the effect of applying NPK fertiliser to seedling growth.
4) Rooting and shooting ability of *P. angolensis* cuttings of mid-diameter sizes 1.9 - 4.9 cm (this study was conducted in Kitwe, Zambia).

2. Literature review

This chapter contains a literature review of *P. angolensis.* The general description, distribution, morphology, silvicultural characteristics, ecological and physiological factors, uses, vegetative propagation, tree improvement, timber qualities and properties are discussed.

2.1 General description and distribution

Pterocarpus angolensis DC. belongs to the pea family Fabaceae (Syn. Papilionaceae), a subfamily of Leguminosae. It belongs to a genus comprised of about 100 species of which four of these occur in the northern and eastern parts of southern Africa (Palgrave, 1956; Dyer, 1975; Lawton, 1978; Storrs, 1982; Vermeulen, 1990; Moll and Moll, 1994 and Storrs, 1995).

P. angolensis is a typical savannah and forest tree species (Vermeulen, 1990) specifically found in tropical, sub-tropical and in south-central Africa (Fig. 1) (Vermeulen, 1990 and Mbuya *et al.*, 1994).

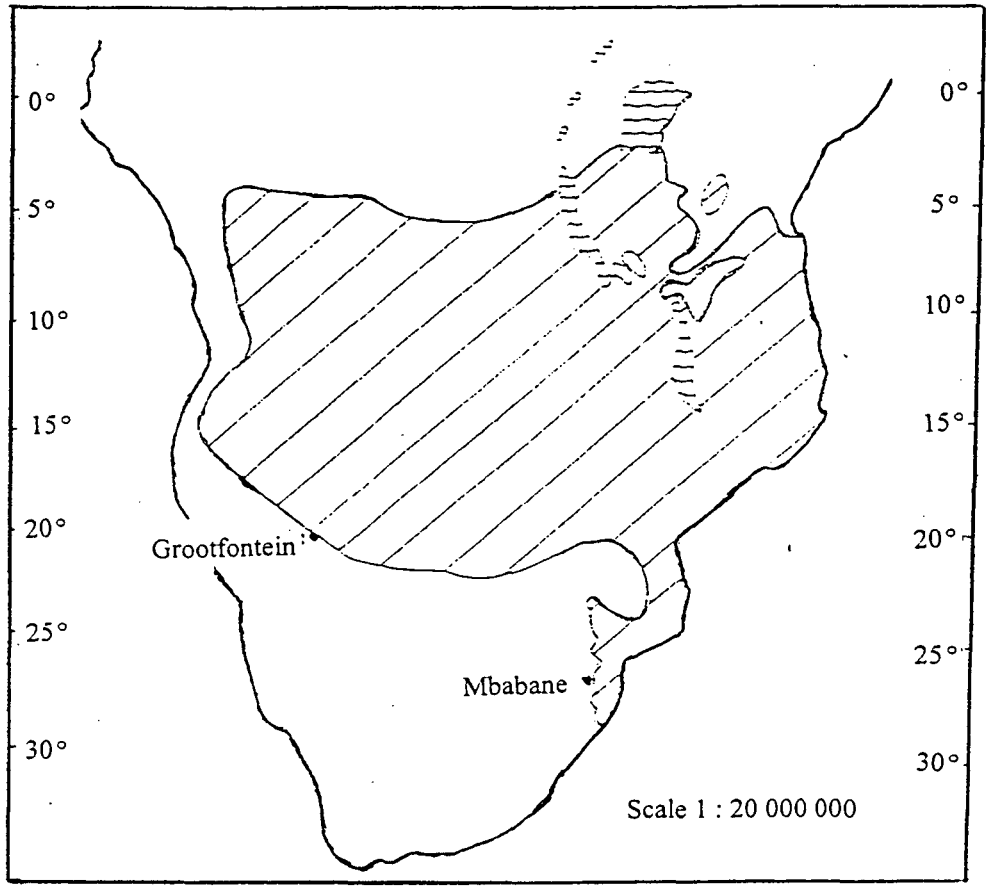


Fig. 1. Distribution of *P. angolensis*. Areas in which the species occurs are shaded. Source: Vermeulen (1990).

P. angolensis natural distribution is limited by climatic factors. In the north, it does not enter the two season rainfall areas such as Kenya and Uganda (Boaler, 1966) and in the south, it does not occur in cold areas and those areas with well distributed rainfall (Palmer, 1981 and Bleys *et al.*, 1982) such as the three Cape provinces (East, West and North West) in South Africa. In Tanzania, it is however reported by Boaler (1966) and Mbuya *et al.* (1994) to be found in most regions with varying climates as long as soils are well drained.

P. angolensis grows naturally in the following areas; Angola (the coastal belt), Botswana (Chobe and the upper Tati Districts), Malawi (the escarpments and both sides of the Shire valley to the south), Mozambique (Manica, Sofala, Beira, Inhaminga and Buzi Districts), Namibia (Caprivi, Kavango and Ovambo), South Africa (Lowveld of Mpumalanga and Northern Province, Kwa Zulu-Natal), Swaziland (no detail information of the distribution of the species is available), Tanzania (Kilwa, Lindi, Morogoro and Tabora), Zambia (throughout the country), Democratic Republic of Congo (Kwilu-Kasai of the Congo basin and the Katanga province) and Zimbabwe (Gokwe and Matebeleland) (Scott, 1941; Stapleton, 1955; Groome *et al.*, 1957; Nkaonja, 1982; Vermeulen, 1990; Simute, 1992 and Mbuya *et al.*, 1994).

2.1.1 *Common names*

The species has numerous common names in different parts of its geographical range. It is difficult to pick out which name is most preferred in each country. In Zambia for example, several names exist and the two mentioned are not the only important ones. The common names are; Girasonde, Mirahonde (Angola), Kiaat (South Africa), Mlombwa (Malawi), Mokwe (Botswana), Mutondo-Mashi (Democratic Republic of Congo), Mukwa (Zimbabwe), Umbila (Mozambique), Mukwa, Mulombwa (Zambia), Mninga (Tanzania) (Groome *et al.*, 1957; Vermeulen, 1990; Simute, 1992; Mbuya *et al.*, 1994; Munyanziza, 1994 and Storrs, 1995).

2.1.2 *Associated tree species*

In nature, *P. angolensis* tends to grow in association with other tree species. These associated tree species vary from one geographical region to another.

In the tropical deciduous savannah woodland of Angola, Mozambique, Democratic Republic of Congo and Zambia, *P. angolensis* grows in association with trees of the family *Caesalpiniaceae* (*Brachystegia*, *Julbernadia* and *Isoberlinia*). The associated tree species tend to dominate the canopy (Groome *et al.*, 1957 and Vermeulen, 1990) making early establishment of *P. angolensis* difficult.

In the Kavango-Zambezi areas of Namibia, *Baikiaea plurijuga*, *Burkea africana*, and *Dialium angleranum* are some of the species found growing with *P. angolensis*. In South Africa, *P. angolensis* grows with *Burkea africana* and non-*Caesalpiniaceous* bushveld species such as *Sclerocarya birrea*, *Parinari curatellifolia*, *Pseudolachnostylis maprouneifolia*, *Terminalia sericea* and *Combretum* species (Vermeulen, 1990).

In the natural forests of Malawi, *P. angolensis* grows with *Pericopsis angolensis*, *Burkea africana* and *Alfzelia quanzensis* as over-storey species. Common under-storey species include *Dalbergia nitidula* and *Oxytenanthera abyssinica* (Groome *et al.*, 1957; Edwards, 1981, unpublished report and Nkaonja, 1982).

In Swaziland, *P. angolensis* grows in association with *Sclerocarya birrea*, *Parinari mobola* and *Diospyros mespilis* (Groome *et al.*, 1957).

2.1.3 *Associated bacteria and fungi*

In nature, *P. angolensis* forms nodules. The bacteria found in its nodules belong to the genus *Rhizobium* (Storrs, 1982 and Munyanziza, 1994). The species is capable of fixing atmospheric nitrogen although the extent to which the fixed nitrogen is beneficial to the trees is not known and yet to be researched. Mbuya *et al.* (1994) reported leaves of *P. angolensis* containing 50% more nitrogen than the non-nodulating associated tree species, *Julbernardia globiflora.* The high nitrogen content was said to be due to nitrogen fixation. The species grows in symbiotic association with vesicular arbuscular mycorrhizal fungi (Munyanziza, 1994). The fungal species names have not been found in literature. According to Bowen and Nambiar (1984) and Vermeulen (1990) the fungal hyphae grow into the rhizosphere and into the soil but do not form a sheath around the root or produce marked changes in root morphology. The hyphae grow between the cortical cells forming vesicles and finely branched arbuscules. The arbuscules are responsible for transfer of nutrients to the root and of sugars and other metabolites from the root to the fungi. Mycorrhizal symbiosis increases especially phosphorous uptake by the host plant (Bowen and Nambiar, 1984; Theron, 1991).

2.2 General morphology of the tree

2.2.1 *Leaves*

P. angolensis is reported by many authors to have alternately or sub-opposite compound leaflets ranging from 4 to 12 pairs along the leaf stalk (Vermeulen, 1990; Simute, 1992 and Mbuya *et al.*, 1994). The number of leaves per stalk vary but may go up to 8. The shape of the leaves is ovate to ovate-oblong with entire margin. The leaflets are usually drooping and hairy on the upper surface (Palgrave, 1988 and Storrs, 1995). The upper surface of the mature leaf is generally dark green and the under surface is duller and paler in colour (Stapleton, 1955; Groome *et al.*, 1957; Boaler, 1966 and Simute, 1992). Minute glands exist on the under surface of the leaves (Graz, 1996, unpublished report).

The leaves of *P. angolensis* are deciduous, dropping early in the dry season. In Zambia for example, leaves start dropping about June to October, hence the tree is without leaves for almost five months (Personal observation). The tree is left without leaves for a longer time than most of its associates. This, among other reasons, may explain why the tree takes such a long time to mature. According to Boaler (1966), Palmer (1981) and Palgrave (1988) in general, new leaves emerge towards the end of the dry season and after the first rains.

2.2.2 *Flowers*

Flowers are produced in several and narrow racemes, mostly on the previous season's shoot before or at the same time as the leaf buds burst (Groome *et al.*, 1957 and Palmer, 1981). On the other hand, Boaler (1966) observed flowering racemes being produced from shoots of current year's growth. Flowering racemes are produced at the base of the first two to three new shoots. Buds take about 5 days to open and fruiting takes place within 3 to 4 weeks after flowers have opened.

The length of the flower varies from 1.2 to 2 cm (Palgrave, 1988 and Vermeulen, 1990). Palmer (1981) reported the flower length of 1.9 cm. Petals are pea shaped, the calyx is cup shaped and stamens are joined together (Palgrave, 1988).

Flowering periods of *P. angolensis* differ from location to location. In Tanzania and Mozambique, it occurs in mid October, Zambia (August to October) and in South Africa (September to October) (Vermeulen, 1990). In general, in central and southern Africa,

flowering occurs from August to December. Apart from the species' genetic variations, climatic conditions such as weather, temperature and site characteristics such as soil nutrient status, moisture and texture could be responsible for the differences in flowering periods.

Flowers are mainly insect pollinated especially by bees. Wind plays a role in pollination although strong wind tends to blow away flowers. Flowers of *P. angolensis* produce the best and finest honey among leguminous species (Storrs, 1982).

2.2.3 *Fruit*

Trees may bear fruit at the age of 20 years though fruiting could be light until at the age of 35 years (Boaler, 1966). Fruit production goes on practically every year until the tree dies. The number of fruit produced per tree increases with the degree of canopy openness (Bleys *et al.*, 1982).

Fruit production takes place on new shoots in the outer part of the crown during the early rains and ripen slowly during the rainy season and the following dry season (Vermeulen, 1990). Fruits tend to persist in large numbers on a leafless tree during the dry season. In Zambia, fruits ripen between April and June. Ripe fruits are dispersed by wind.

The number of fruits vary from tree to tree and from year to year. The only records available show 100 to 400 fruits per tree with 1 to 6 drooping pods per raceme at Handeni site, eastern Tanzania (Boaler, 1966). In productive years however, fruit production may be even higher than reported figures. Boaler (1966), Bleys *et al.* (1982) and Munyanziza (1994) reported on the percentage of fruits containing seeds usually to be about 50%.

The pod size, shape, and number of seeds per pod vary from tree to tree and from provenance to provenance. Mostly, the pods are large, flat, round to oval shaped and hard winged. They contain about 0 to 3 seeds. The pods are bulky, hairy and covered with harsh bristles up to 1.3 cm in length (Plate 1 and Fig. 2) and are indehiscent (Boaler, 1966; Palmer, 1981; Palgrave, 1988; and Storrs, 1995). There are three other genera other than *Pterocarpus* in the southern region with pods without harsh bristles (Moll and Moll 1994). These could play a major role in tree improvement of *P. angolensis* pods.

Plate 1. Ripe *P. angolensis* pods from the miombo woodlands, Kitwe, Zambia.

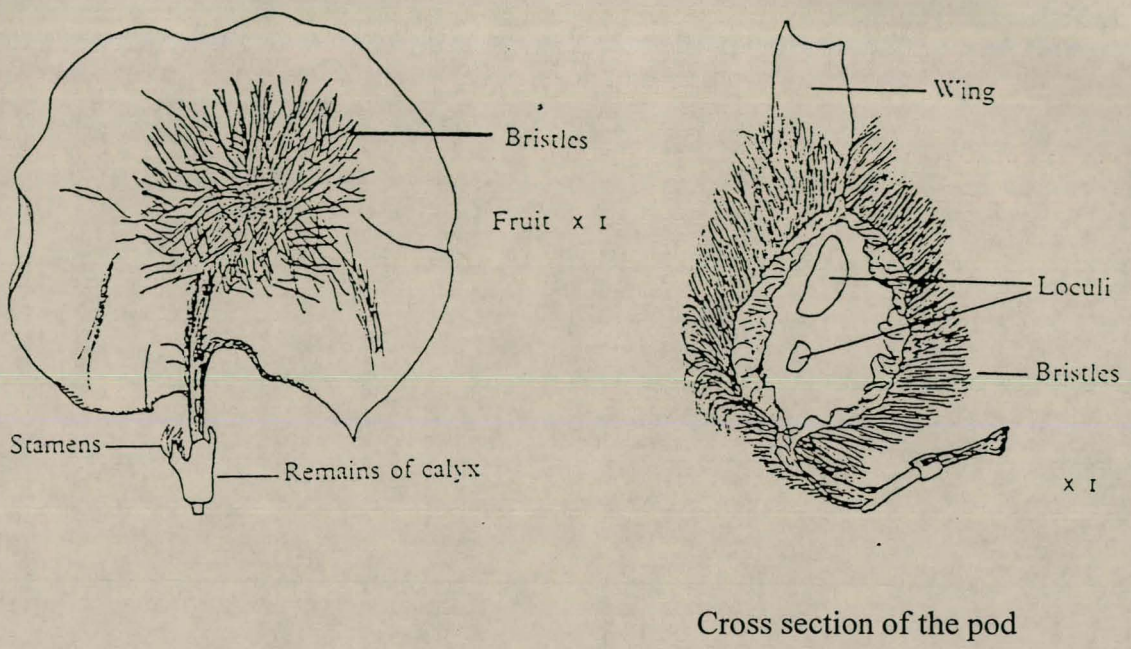


Fig. 2. Diagrammatic representation of a mature *P. angolensis* pod.
Source: Vermeulen (1990).

2.2.4 *Seeds*

The number, colour, size, weight and shape of seeds vary over the geographical range of the species' distribution and from tree to tree. For example, some samples of seeds from different provenances were weighed to determine their number per gram. Their numbers varied and were as bracketed; Chimanimani (6), Masese (7), Mtao (7), Solwezi (9), Bushmanland west (5) and Mufumbwe (5). Mufumbwe provenance had heavier seeds than Solwezi provenance yet both provenances are found in North Western province, Zambia (Personal observation). Mbuya *et al.* (1994) reported number of seeds per kilogram of between 3 400 and 5 000. Generally, seeds are smooth, shiny, very hard with colour ranging from brown to dark brown and red brown (Palgrave, 1988 and Van Daalen, 1991). An example of seeds sampled for colour variations between provenances is that of Masese (light brown colour), Solwezi (very dark brown), Mufumbwe (mixed from light brown to dark brown) and Chimanimani (darkish brown) (Personal observation).

2.2.5 *Bark*

The bark is dark grey to brown, rough and longitudinally fissured (Palgrave, 1956 and Palmer, 1981). Moll and Moll (1994) reported a blackish trunk with deep scales.

2.2.6 *Life span*

The life span of *P. angolensis* is suspected to be 60 to 90 years (Boaler, 1966). But in some sites like on the Copperbelt, Zambia, trees live beyond 100 years. Under natural conditions, little increase in height occurs after about 60 years (Kambala, 1982, unpublished report and Vermeulen, 1990). At this age, concentration of growth is more in diameter growth.

2.2.7 *Heartwood and sapwood*

Heartwood formation begins at about 15 years, increasing steadily until 35 years when formation slows down. The proportion of the heartwood across the tree's diameter is about 75 - 80% from 50 years of age onwards. The percentage of sapwood especially on small logs is quite high, about 30% in volume (Boaler, 1966; Kambala, 1982, unpublished report and Vermeulen, 1990).

2.2.8 *Height, diameter and crown growth*

Over a greater part of its range, *P. angolensis* is a medium-sized tree with a straight cylindrical bole. Main limbs branch out into several straight and steeply rising branches supporting a thin foliage. Usually, the crown spreads out like an umbrella (Plate 2 and 3).

The dimensions of mature trees vary considerably over the species' geographical range and from site to site within the same geographical region. The tree is usually between 10 to 12 meters tall. On very good sites it may attain heights of 15 to 20 meters with a bole of 4 to 8 meters long and of 0.6 meters in diameter (Palgrave, 1956; Boaler, 1966; Vermeulen, 1990 and Storrs, 1995). The tallest specimens were found in Mozambique (Vermeulen, 1990) and Zambia (Storrs, 1995) where trees of 25 and 28 meters respectively have been reported. On the Copperbelt, Zambia, where the specimen was found, soils are deep, well drained and rich in organic matter explaining the extraordinary height. However, this height is not common in all parts of the country. Groome *et al.* (1957) reported that the mean bole length is 57% of total height in Mozambique and 50% in Tanzania.

In South Africa, *P. angolensis* seldom attains 12 meters height. It has a straight bole with branches from low down and up to about 0.6 m diameter (Palmer, 1981 and Palgrave, 1988).

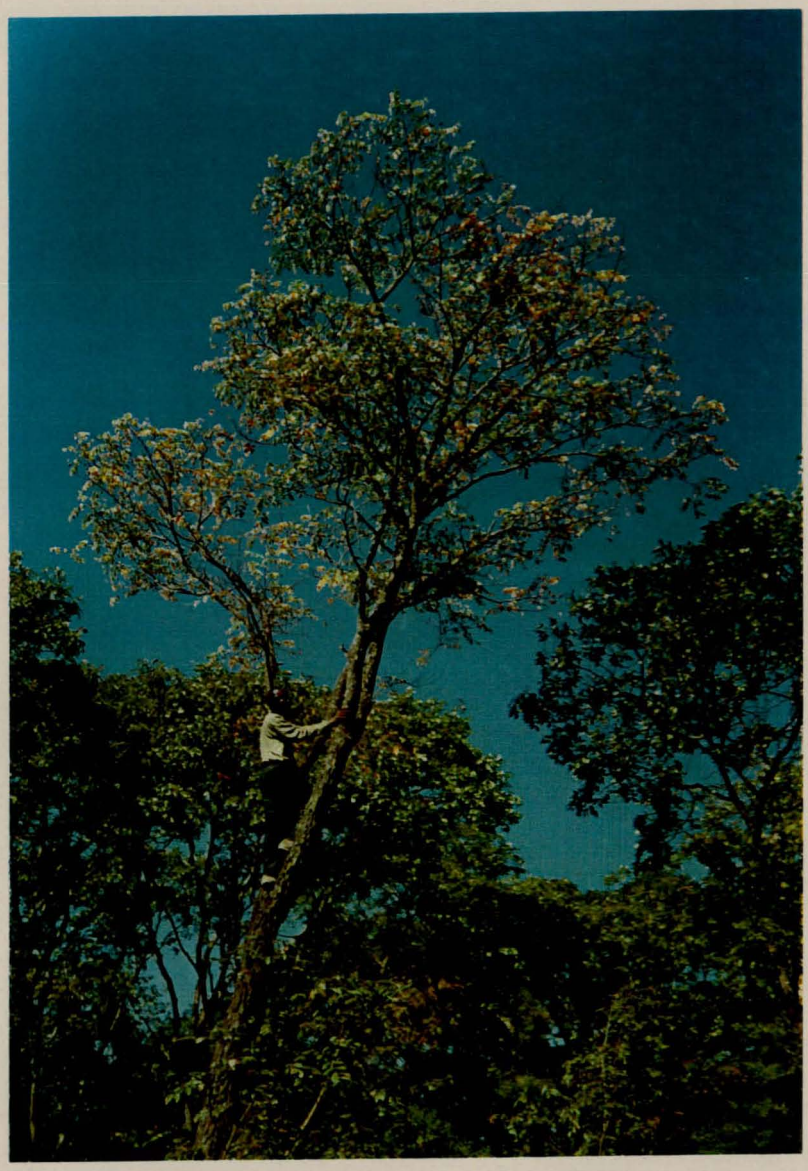


Plate 2. A tall and straight cylindrical specimen of *P. angolensis,* Kitwe, Zambia.

Plate 3. *P. angolensis* specimen with yellowish - brown leaves thinly spaced and about to be shed in the miombo woodland Kitwe, Zambia.

2.3 Ecological and physiological factors

2.3.1 *Physiological factors*

Little information on the influence of physiological factors such as aspect and slope on the distribution of the species is available. However, from the literature available it appears

physiological factors impose little, if any limitation on the distribution of *P. angolensis* within its altitudinal and climatic range. According to Nkaonja (1982) and Vermeulen (1990) basic soil requirements are more influential.

2.3.2 *Soil factors*

The miombo woodland where *P. angolensis* is found, has sandy top soils, low in nutrient content and high pH. *P. angolensis* has a greater preference for alkaline, light textured, more permeable, good depth and free drainage soils. The species does well on soils whose physical characteristics permit water to drain rapidly down the profile through the top 30 cm and are well aerated. The species is however found on a considerable range of rock types, hill slopes, escarpments and soils newly derived from the parent rock (Palmer, 1981 and Nkaonja, 1982). Insufficient data is available to relate rock type and *P. angolensis* performance (Groome *et al.*, 1957; Boaler, 1966; Edwards, 1981, unpublished report and Palgrave, 1988).

Stag-headed appearance occurs once the species grows on shallow, sandy, clayey, dambo and water logged soils (Palgrave, 1988 and Van Daalen *et al.*, 1992).

2.3.3 *Climatic factors*

P. angolensis performs well with mean temperature of the warmest month > 20°C and minimum mean temperature of the coldest month > 4°C (Boaler, 1966 and Vermeulen, 1990). *P. angolensis* can grow under extreme dry conditions once established but prefer dry sub-humid regions with single annual rainfall season of between 500 - 1 200 mm. Seedlings are injured by frost where as mature trees are not (*Groome et al.*, 1957; Nkaonja, 1982 and Vermeulen, 1990).

2.3.4 *Demand for light*

P. angolensis is a strong light demander. Trees growing in the open are able to reach very large sizes, produce timber at a fast rate and produce shoots of the order of 1 m length each growing season (Trapnell, 1959 and Boaler, 1966). Trees in the open fruit more frequently and more heavily than those in the shade. Very heavily shaded plants often persist in their growth but usually become twigs, slender and eventually die-back completely after growing for 2 - 3 years (Groome *et al.*, 1957 and Boaler, 1966). Other researchers such as Graz (1996,

unpublished report) have reported survival of saplings growing under shade for a number of years. These saplings are said to eventually grow to normal trees after growing conditions are improved like opening up of the canopy.

Groome *et al.* (1957) disputed the fact about seedlings requiring shelter in the nursery as shading appeared to have a negative effect on the growth of nursery seedlings. Seedlings not shaded are said to emerge, grow well and vigorous. Higher mortality is therefore expected in seedlings growing under shade (Groome *et al.*, 1957 and Kambala, 1982, unpublished report). Vermeulen, (1990) recommended openings during early establishment of seedlings and development of saplings.

2.3.5 *Resistance to fire*

P. angolensis is considered to be the most fire resistant species of the savannah woodland and the miombo canopy trees. It is a species that increases in abundance after cultivation of the miombo woodland.

Saplings and big trees appear to tolerate fierce fires and have the ability to coppice after fire attack (Vermeulen, 1990 and Munyanziza, 1994). In the Ndola burning plots, Zambia, *P. angolensis* proved its ability to regenerate and grow in the worst fire conditions. According to Groome *et al.* (1957) and Lawton (1978) land was cleared and burned yearly for over 20 years but still, only *P. angolensis* trees were found growing out of all the miombo species such as *Brachystegia* and *Julbernadia.* Geldenhuys (1977) reported no significant effects in basal area increment of *P. angolensis* after annual fires were introduced to the Makambu forest, Kavango, Namibia. In this experiment, *Baikiaea plurijuga* was more susceptible to fires. However, according to Palgrave (1988) although *P. angolensis* trees are resistant to fires, repeated burning produces a stag-headed appearance. If burning takes place late in the dry season, after the new leaves have emerged, then the new growth would be burnt damaging crowns of the canopy trees. Boaler (1966) reported some 20% loss in shoot growth after some years of burning and abandoning the forests. While the above findings are true, the effect of fire may cause slow development of the seedlings or saplings. The extent of damage and survival of *P. angolensis* trees from fires will also depend on the intensity and frequency of fires.

Trapnell (1959) reported on *P. angolensis* trees increasing on their growth after controlled fires were applied. The other miombo tree species growing in association had no increased growth. The increase in growth could have been attributed to increased supply of mineral nutrients provided by ash. Chidumayo (1987) and Holden (1993) reported changes in soil chemical properties after adding ash. Ash enhances exchangeable bases such as pH values, available phosphorous, potassium, sodium. Efficiency in nutrient uptake by the species and probably changes in micro fauna and floral population after fires might have also led to increased growth of *P. angolensis*.

According to Edwards (1981, unpublished report) successful establishment of seedlings and saplings appears to depend on the absence of fire for the first five to ten years. Example: An investigation in Ovamboland, Namibia, was carried out after fires had been introduced to the forests and very few seedlings, coppices and young trees of *P. angolensis* were found growing in the area due to the effect of fire (Van Daalen, 1991 and Van Daalen *et al.*, 1992).

2.3.6 *Diseases and pests*

Little information about insects damaging living plant material has been published. According to observations done in the Ndola burning plots, Zambia, live seedlings are usually attacked by a tar-spot fungus, *Phyllachosa pterocarpi* though it does no great harm. The wilt disease of crown foliage caused by *Fusarium oxysporum* attacks and kills trees of less than 30 years. *Armillaria mellea* (rotting roots) is common in miombo trees and can cause great damage and even kill plants (Piearce, 1979 and Piearce, 1982 unpublished report). Cockchafer larvae attack the roots of newly germinated seedlings and such attacks are usually fatal if they occur during the first two weeks of the plant's life. Larvae of the insect species *Ptyelus flavescens* and *P. grossus* are responsible for sucking cell sap from the bark of young twigs and from petioles (Vermeulen, 1990). A heavy infestation of these insects could cause branches to dry.

Elephants and wild pigs strip off and chew the bark and rub against mature stems and break saplings (Groome *et al.*, 1957 and Vermeulen, 1990). Otherwise, no other serious animal damage have been reported so far.

2.4 Silvicultural characteristics

2.4.1 *Ability of seed to germinate*

Seed germination is epigeal and under natural conditions, it usually happens inside the opened pods. Under natural conditions, successful germination appears to depend on wild fires to burn the ground vegetation and remove the wings and bristles from pods (Boaler, 1966; Van Daalen, 1991 and Van Daalen et *al.*, 1992). Burning enables pods to easily get in contact with the soil and germinate (Munyanziza, 1994) as long as pods are not severely burnt and damaged.

Pterocarpus angolensis seeds have low germination both under natural and artificial conditions unless scarified. According to Boaler (1966) and Munyanziza (1994), in nature under normal miombo conditions, about 2% of fruits which fall to the ground produce seedlings in a given year out of which, about half of the seedlings die in the first year.

P. angolensis seed has a seed coat imposed dormancy affecting the germination capacity. Seed germination could be irregular if seed is not scarified before sowing. Seedlings of one batch may start germinating from the 3rd week to the 6th month from time of sowing (Nkaonja, 1982). Vermeulen (1990) reported germination under nursery conditions from a sample of good seed to be 40% within 3 - 4 days, another 30% within 21 days and the remaining 30% germinating irregularly taking 3 - 16 weeks or longer. Artificially, seed germination is enhanced by scarification either, physically, mechanically or chemically. In nature, scarification occurs by ingestion of seed by animals, cracking of seed coat by fire, abrasion, water, and rising and falling of temperature.

Under artificial conditions, many scarification methods have been investigated and reported. For example, in Malawi, germination of > 80% was obtained after placing the seed between moistened sterile cloth (Nkaonja, 1982). At the University of Stellenbosch, Faculty of Forestry, South Africa, a germination of 96.5% was obtained after nicking part of the seed coat away from the embryo point using a surgical razor blade (Kasumu, 1996, unpublished report). Mbuya *et al.* (1994) reported seed germination of between 30 - 70% without stating the method used in germinating the seed.

2.4.2 *Vegetative propagation*

Vegetative propagation has been used for several centuries mainly by horticulturists. In forestry, it was reported by Zobel and Talbert (1984) to have been in use for about 100 years. However, research on rooting and shooting of *P. angolensis* cuttings has been done by many researchers without success. The genus *Pterocarpus* easily forms shoots from cuttings but root formation has been found to be difficult. It is reported by Vermeulen (1990) to produce shoots from stumps and low pollards which could take more than 10 years to form permanent saplings. A low survival of truncheons (big stem cuttings) of less than 20% was reported by Nkaonja (1982). According to Trapnell (1957) and Zimmerman (1984) only about 30% of cuttings out of what is planted in the ground could form roots.

Possible benefits from use of vegetative propagation

There are several gains both genetically and economically from the use of vegetative propagation through cuttings. Some of the gains are that desired genetic qualities of selected trees are rapidly obtained by using vegetative propagation (Van Wyk, 1985 and Hibberd, 1991) and also, the none-flowering juvenile phase is shortened (Hodgson, 1977). According to Zobel and Talbert (1984) uniformity of tree stands and quick production of high yielding plantations is expected from vegetatively produced stands. In rooted cuttings, the original parent genotype is retained intact unlike in seed where genes of selected trees are preserved but the original genotype is never intact (Young, 1982).

Several positive results from use of vegetative propagation have been reported by many scientists. One example is that of Brazil and Congo where French researchers developed clonal forestry to a commercial scale using a hybrid of *Eucalyptus platiphyla* (Van Wyk, 1985). According to Denison and Quaile (1987) cuttings taken from a desirable plus phenotype may be massively produced on a large scale for commercial planting.

2.4.3 *Suffrutex stage*

P. angolensis seedlings suffer from annual die-back after germination. The shoots of the plants die-back in some cases to ground level each dry season and during cold months. In the miombo woodland, new shoots develop during the following rain season. This condition is called the suffrutex stage (Boaler, 1966). At Lupa, Tanzania, it was discovered that the proportion of shoot dying back was 10% in plants growing in the open and 85% in plants growing in woodlands (Boaler, 1966 and Vermeulen, 1990). In Zambia, the proportion of

die-back was estimated to be 30% (Groome *et al.*, 1957). The die-back habit of *P. angolensis* was further confirmed in a survey at the Mua-Livulezi Forest Reserve, Malawi, where forests were guarded against fire for some time (Edwards, 1981, unpublished report and Nkaonja, 1982). The same observation of seedlings dying back was made on 252 seedlings which were 11 months old by May, 1997, growing in the University of Stellenbosch, Faculty of Forestry nursery. All the leaves were shed from all the plants at the beginning of winter in May leaving only stems standing bare showing no sign of life (Fig. 3). Leaf buds started opening in mid September (spring) (Figs. 4 and 5).

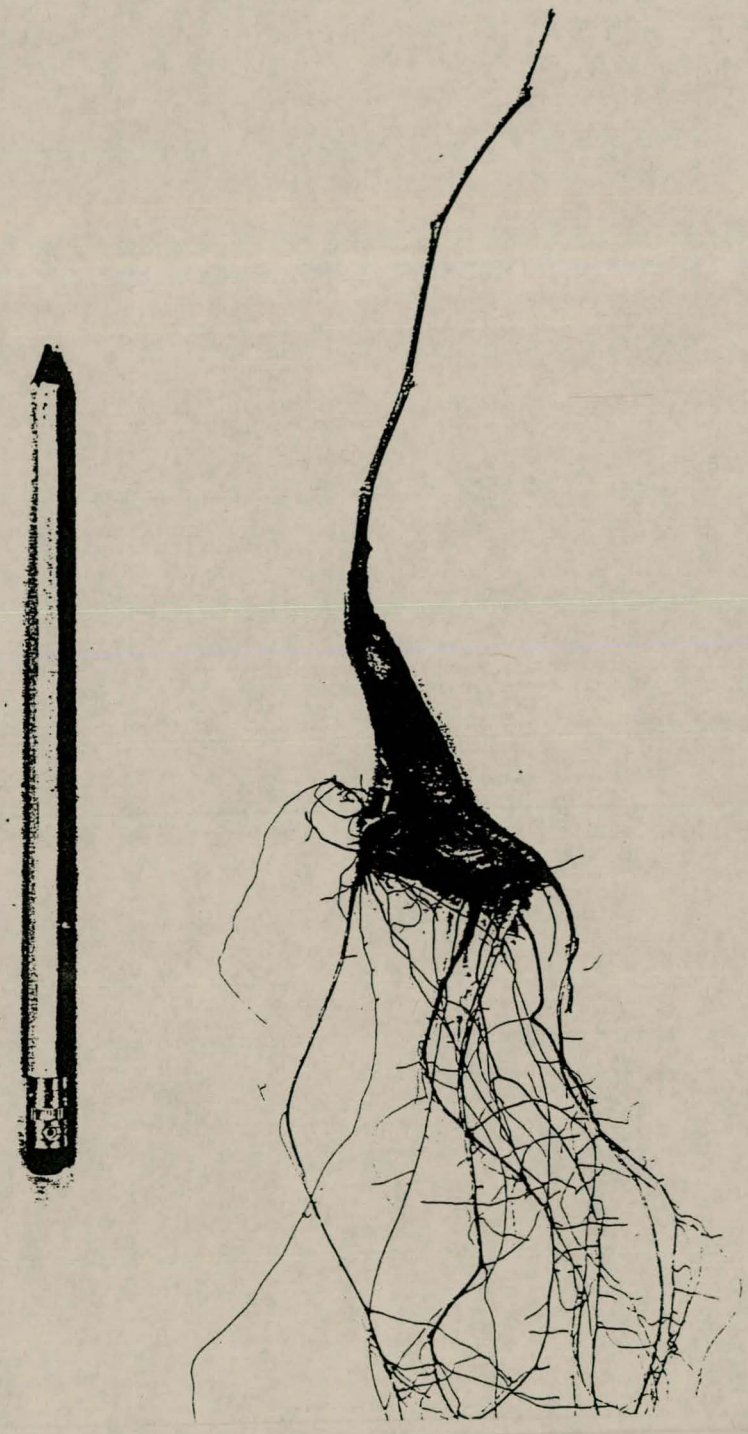


Fig. 3. Diagram of 11 months old *P. angolensis* seedling with all the leaves shed during winter period (May-August). Note how the root system is dominated by the tap root. The size of the picture is 65% of the original plant size.

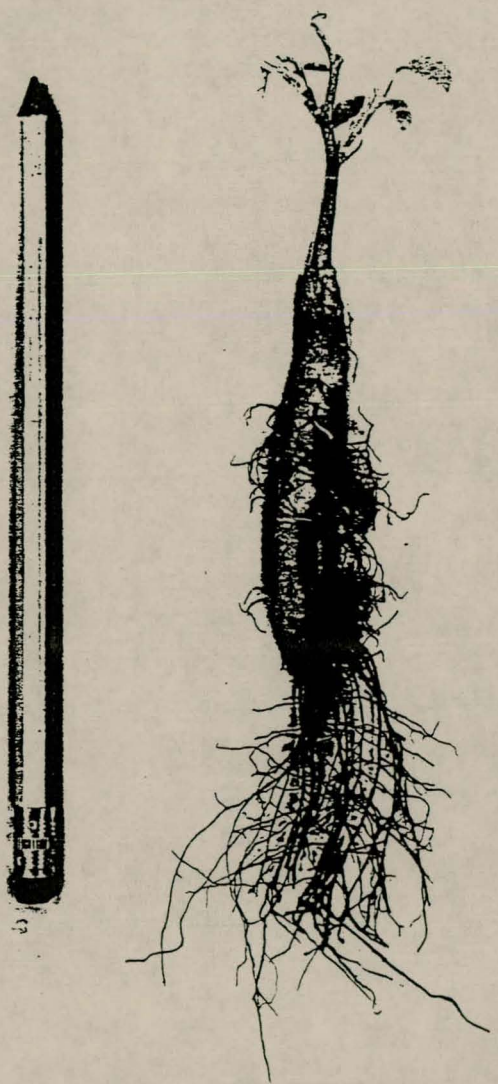


Fig. 4. Seedling of 11 months old *P. angolensis* opening up leaf buds in spring (September). The size of the picture is 65% of the original plant size.

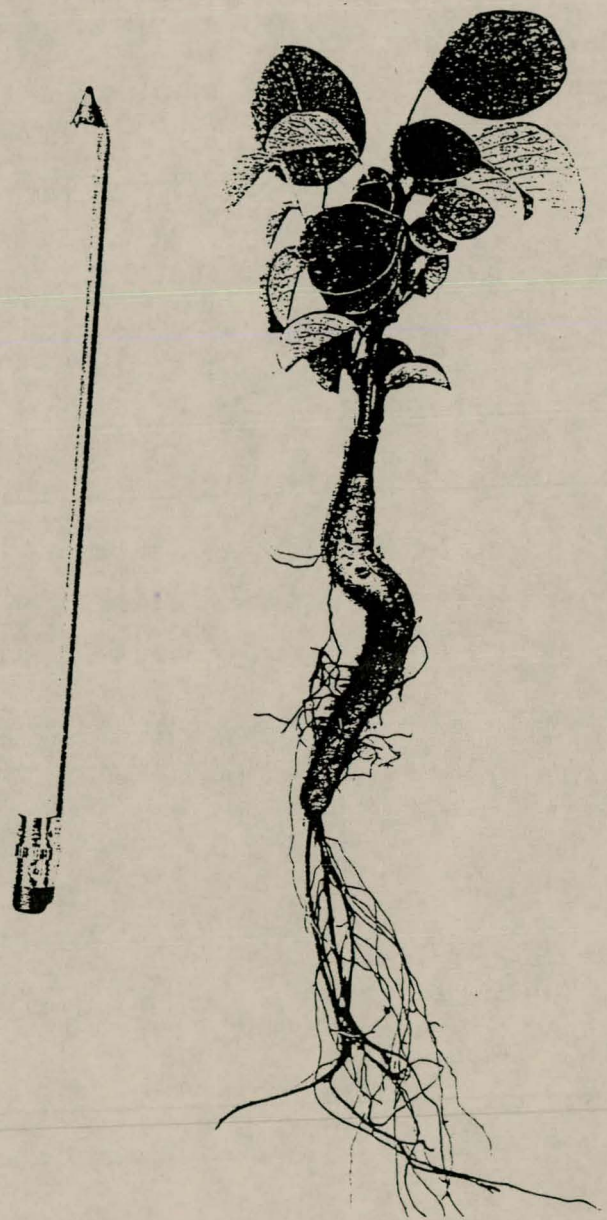


Fig. 5. Seedling of 11 months old *P. angolensis* showing fresh leaves formed after the die-back period. The size of the picture is 65% of the original plant size.

The suffrutex stage takes up to 12 years and longer or until the root system is large enough to collect sufficient water and nutrients for survival. During this stage, the root system concentrates on elongation (Figs. 3 to 5). After the suffrutex stage, the sapling continues to grow and concentrate mainly on shoot growth and energy is then directed to height growth and root penetration rather than to diameter growth (Groome *et al.*, 1957; Boaler, 1966; Von Breitenbach, 1973; Vermeulen, 1990; Van Daalen, 1991 and Munyanziza, 1994). During the suffrutex stage, shoots do not grow straight because of the effect of die-back. Shoots of successive growing seasons grow alternately.

In miombo stands, 90% of woody plants are suffrutex (Boaler, 1966) and it is these suffrutex plants which provide replacements for lost canopy trees.

2.4.4 *Root system*

The taproot of *P. angolensis* is well defined (Boaler, 1966) and fast growing (Figs. 3 to 5). And in a study carried out in Kavango, Namibia, it was found that within the first 10 years of the suffrutex stage seedlings were able to grow on average a taproot of 760 mm with lateral roots spreading up to 731 mm (Von Breitenbach, 1973). In Tanzania, the mean taproot length of 450 - 910 mm was reported by Boaler (1966). However, root growth varies from site to site and from individual to individual tree. The taproot is very important for nutrient and water uptake especially in the early stages of development for the survival of seedlings.

2.5 Tree improvement of the species

Research on tree improvement and forest genetics has been in existence for over 150 years (Wright, 1976) but not much has been done on indigenous tree species such as *P. angolensis* in Africa. Many researchers have concentrated on improving exotic tree species such as Pines and *Eucalyptus*. Yet there are several important economic advantages tree improvement activities such as provenance and family trials may bring to indigenous species. A few examples are: in South Africa, provenance trials were used to discover the best provenance of *P. pinaster* of the Portuguese strain. This was 42% better in volume production than its nearest competitor, the South African Landes race at ten and a half years (Van Wyk, 1983).

According to Mullin *et al.* (1981) in Zimbabwe, all material for initiating a breeding programme of *Eucalyptus camaldulensis* was obtained from Australian provenance trials and Zimbabwean seed sources. The Australian provenance was found to be best adapted to local harsh conditions and was used. Provenance trials have also been used in assessing fodder quality and leaf production of *Calliandra calothyrsus* for a range of provenances (Dick *et al.*, 1996).

2.6 Timber quality and properties

P. angolensis timber has valuable properties and attractive appearance. The grain and colour of the timber vary from piece to piece but the colourings and markings are often beautifully blended in the same board. The heartwood is light brown to reddish brown often with a pink or purple cast and with darker streaks. The sapwood is pale yellow in colour (Groome *et al.*, 1957 and Vermeulen, 1990).

The moisture content of green timber usually varies from 70 to 80%. The timber seasons well but relatively slowly. Shrinkage on drying is low, usually 12% with little or no tendency towards splitting, warping or distortion, and the knots remain tight in the wood. Scott (1941) and Vermeulen (1990) gave an example of a 25 mm board seasoning in the open to 12% moisture content in 3 - 4 months with practically no defects.

P. angolensis wood finishes well and works readily in all hand and machine operations. The wood saws easily and slices neatly, glues and turns well, sands to a reasonably smooth surface, polishes and paints well. In general, it has good nailing and screwing properties and takes a fine polish. The grain is rarely straight having an irregular interlocking grain which often enhances the natural figure making the timber remarkably beautiful (Scott, 1941; Groome *et al.*, 1957; Nkaonja, 1982; Simute, 1992 and Mbuya *et al.*, 1994).

The tangential and radial shrinkage are about 1.5 and 1% respectively indicating very high stability (Groome *et al.*, 1957). Timber is of medium weight and slightly harder than teak, the average density is from 650 - 1 075 kg per m^3 for green timber and 440 - 680 kg per m^3 for air dry timber (Vermeulen, 1990).

The heartwood is resistant to wood-rotting fungi, attack by termites, ants, terrestrial and marine borers where as the sapwood is not. The dry sapwood is susceptible to borer and beetle (*Bostrychidae* and *Lyctidae*) (Scott, 1941; Boaler, 1966 and Piearce, 1982). The extent of timber durability varies from tree to tree (Palgrave, 1956; Bleys *et al.*, 1982; Vermeulen, 1990 and Mbuya *et al.*, 1994).

2.7 Uses

In the parts of Africa where *P. angolensis* is found, nearly all parts of the tree are utilised for medicinal purposes by the indigenous people and for commercial timber production.

Some of the domestic uses are: stimulation of lactation once the bark is mixed with figs, remedy for nettle rash, relief of stomach disorders, cure for headaches and mouth ulcers, treatment of burns and gonorrhoea, making of a permanent dye from the red sticky sap and cure for nose bleeding (Palgrave, 1988 and Vermeulen, 1990). Apart from the above mentioned uses, in Zambia, *P. angolensis* is also used for making dishes, mortars and drums. According to Storrs (1995) its tannin is mixed with castor oil to make a body paint. The resinous sap is used as a fish poison in North Western Province, Zambia.

P. angolensis yields one of the widely used timbers of the African continent. Its reddish to brown heartwood timber is commercially used in making high quality furniture, joinery, parquet flooring, boats, canoe paddles, panelling, veneers, framing, decorative work of all sorts, railway sleepers, general construction work, utility plywood and turnery (Scott, 1941; Palgrave, 1956; Groome *et al.*, 1957; Palgrave, 1988 and Van Daalen, 1991).

The durability and low shrinkage of the heartwood makes it a particularly suitable wood for exposed positions and one of the most suitable timbers for use in the building industry (Vermeulen, 1990). It is suitable for situations such as bridge making requiring stable, strong and durable timber. It is a good substitute for teak in exposed conditions.

3. Materials and methods

In this chapter, materials and methods used in provenance, family and vegetative propagation trials of *P. angolensis* are discussed. Seed sources, experimental designs, treatments, pot size, watering, temperature, chemical application, method of assessment and statistical analysis procedures for all the three trials are explained.

3.1 Provenance trial

3.1.1 *Seeds*

Seeds were collected from Chimanimani (Zimbabwe), Masese, Mufumbwe and Solwezi districts (Zambia).

Chimanimani (18° 13′ S; 28° 56′ E), has an altitude of 1 190 meters above sea level (asl). The mean annual rainfall is 890 mm. Mean daily temperatures for May are approximately 18^{0}C minimum (min.) and 24°C Maximum (max.). Seed collection was done in May, 1996. The average weight was 70.14 grams per 320 dry seeds.

Masese (17° 28′ S; 24° 18′ E), has an altitude of 1 000 meters asl. The mean annual rainfall is between 662 - 959 mm. Mean daily temperatures for May are 8°C min. and 28°C max. Seed collection was done in August, 1995. The average weight was 58.66 grams per 320 dry seeds.

Solwezi (12° 11′ S; 26° 25′ E), has an altitude of 1 200 meters asl. The mean annual rainfall exceeds 1 100 mm. Mean daily temperatures for May are 10.5°C min. and 25°C max. Seed collection was done in June, 1995. The average weight was 54.46 grams per 320 dry seeds.

Mufumbwe (11° 44′ S; 24° 26′ E). Refer to Solwezi for the altitude, rainfall, temperature and seed collection dates. The average weight was 59.2 grams per 320 dry seeds.

In all areas, seed collection took place during the range wide collection by the SADC Tree Seed Centres supported by CIDA. Seeds were collected from mature plus trees of *P. angolensis* which were about 100 meters apart and naturally growing in the areas.

All seeds were fumigated with phosphene fumigant for five days and then stored dry in the cupboard under room temperature.

3.1.2 *Experimental design*

The study was carried out in the Faculty of Forestry nursery, University of Stellenbosch. A randomised complete block design with sixteen treatments in a 2 x 2 x 4 factorial treatment design with twenty replicates was used. Each treatment had four plants in a replicate. Altogether, there were 1 280 seedlings in the experiment. The treatments were assigned to plots at random using tables of random permutations (Green, 1968).

3.1.3 *Treatments*

Black humic soil collected from Somerset-West and building sand from Malmesbury were mixed at a ratio of 1:1 to form a mixture of soil which was used to raise seedlings. The mixture of soil was chemically analysed (Table 3.1).

Treatments included two levels of soil sterilisation in combination with two levels of soil inoculation with soil presumed to contain mycorrhizal fungi.

Before sowing, each seed was nicked with a surgical blade at one edge away from the embryo point to remove part of the seed coat. Each seed was sown at 1.5 cm depth.

a) *Soil inoculation*

The inoculum used was unsterile soil from the rhizosphere of *P. angolensis* naturally growing near Nelspruit, South Africa. No study was conducted to assess the mycorrhizal fungal status of the soil, but it was presumed to contain endomycorrhizal fungi since it was collected from a stand of *P. angolensis* trees. According to Shepherd (1986) raw humus from forest stands usually contain mycorrhizae fungi associated with that particular tree species found in the area. Soil collected from Somerset-west was presumed not to contain endomycorrhizae associated with *P. angolenis* since it was obtained from a farm where *P. angolensis* does not grow at all. Fifteen and a half cm of each pot was filled with a mixture of black humic soil and building sand, where after 194.5 grams of the soil inoculum was added to each pot making a filling of 20 cm. The rest of the 6 cm was then filled with the same soil as that at

the bottom of the pot. The soil used as inoculum was analysed for its exchangeable cations before using it (Table 3.1).

b) *Soil sterilisation*

Soil sterilisation was done at the Agriculture Research Council - Plant Protection Research Institute, Stellenbosch. The soil mixture of black humic soil and building sand was loaded in 15 litre metal buckets but not covered and left in the soil pasteuriser with doors tightly closed for 3 hours. The temperature during steam sterilisation was 81°C.

Table 3.1. Exchangeable cations for black humic soil, inoculum and a mixture of sand and humus used in the nursery for growing of seedlings.

	EXCHANGEABLE CATIONS							
SOIL TYPE	P Mg/l	KCl pH	resistance ohm	Calcium me/100g	Magnesium me/100g	Sodium me/100g	Potassium me/100g	C.E.C. me/100g
Black humic soil	11	4.1	1420	0.2	0.11	0.01	0.05	6.48
Soil used as inoculum	11	4.4	1130	1.37	0.66	0.04	0.23	3.63
sand and humus	4.32	7.4	365	13.43	1.16	0.38	0.2	2.9

3.1.4 *Pot size*

All pots were cylindrical, polythene, black and closed at one end (26 cm long x 24.0 cm diameter width).

3.1.5 *Watering and temperature*

Watering of plants was done automatically by sprinklers twice a day (at 7:30 and 16:30) for 4 minutes in summer up to end of May 1997. Plants were starved of water for 5 days to drain excess moisture just before changing the watering schedule. In winter (from 1st week of June 1997) watering was reduced to 2 minutes every other day. This was done to avoid water logging since evapotranspiration was presumed low due to cool temperatures. At the

beginning of summer (second week of October 1997) the watering schedule was again changed to 5 minutes every other day. The average noon temperatures in the nursery were 31.5°C max. and 15°C min. in summer days. In winter days, average noon temperatures were 24°C max. and 9°C min.

3.1.6 *Chemical application*

On 29th May, 1997 all plants were sprayed with a chemical cyhexatin 600 SC to get rid of red spiders. The chemical was applied at the rate of 50 ml / 100 litres of water.

3.1.7 *Assessments*

3.1.7.1 *Seed germination*

A percentage of germinated seeds at 16 days after sowing was calculated for each provenance. Means were separated using Duncan's multiple range test. A t-test on seed mass was done to determine if there were significant differences in seed mass between provenances under study. α=0.05 and a critical level of 2.776 were used.

3.1.7.2 *Height, leaf count and root collar diameter measurements*

The first, second and third height measurements were carried out when seedlings were 49, 105 and 217 days old from time of sowing the seed. Height growth rates were measured with a ruler to the nearest centimetre. Leaf count assessments were carried out at 49 and 105 days of seedling growth by physically counting the number of leaves per plant. Root collar diameters were taken just above the soil level with an electronic calliper, to the nearest 0.1 mm at 217 days from time of sowing the seed.

3.1.7.3 *Above and below ground biomass yield*

Above and below ground biomass production was assessed once when seedlings were 217 days old. It was determined by getting oven dry biomass weight to the nearest gram. One plant per replicate, per treatment was used in the biomass study. Altogether, 25% of total seedlings were sampled for biomass production. Each plant had soil washed off its roots using cold tap water. A sieve was used to hold plants when washing to avoid root loss. Immediately after washing the roots, each plant was put in a clear plastic bag then stored in

the fridge for 15 hours (overnight preservation). The following day, each plant had the above ground biomass separated from the below ground biomass. The above ground biomass was considered any part of the plant above the soil level. Stems and leaves were taken together as above ground biomass. The tap root and all other roots were taken as below ground biomass. After separating the above from the below ground biomass, each sample was placed in a paper pack and oven dried at 80° C for 24 hours for dry weight estimation.

3.1.7.4 *Seedling survival*

A percentage of seedlings which had died in each provenance was calculated. A t-test was done on the mortality percentage using α=0.05 at a critical level of 2.776. Seedling survival assessments were done when seedlings were 217 days old.

3.1.8 *Statistical analysis*

Data were statistically analysed using the Statistical Analysis System (SAS) programme, release 6.07 TS305 SAS institute Inc. (1989). Microsoft Excel Programme for windows 95, version 7.0a (1995) was also used for the spread sheet, drawing of graphs and tables. Normality tests were done on all variables measured to check the skewness of the data. Prior to statistical analysis, data for total leaf count and seed germination were transformed. Square root of the leaf count added to one was used i.e. $\sqrt{(X+1)}$ (Snedecor and Cochran, 1989). Data for seed germination were transformed using square root of the number of germinated seed per treatment (Hasted *et al.*, 1993 and Ott, 1993). Transformed values obtained were used in performing the analysis of variance (ANOVA).

The ANOVA for soil treatments was based on the model:

Yield = overall mean + treatment effect + residual

$$y_{ijk} = \mu + T_{ij} + e_{ijk}$$

for the k^{th} plot with inoculation level i and sterilisation level j.

However, the treatment effect T_{ij} can be further specified in terms of factorial effects, and replications (R) can be included to expand the model to

$$y_{pijk} = \mu + R_p + M_i + S_j + (MS)_{ij} + e_{pijk}$$

Where M_i = the main effect of inoculation level i

S_j = the main effect of sterilisation level j

and $(MP)_{ij}$ = the interaction effect.

Further expansion to include provenance effects (P) and respective interactions will give the full model

$$y_{pqijk} = \mu + R_p + P_q + M_i + S_j + (PM)_{qi} + (PS)_{qj} + (MS)_{ij} + (PMS)_{qij} + e_{pqijk}$$

where

$(PM)_{qi}$ = the interaction effect of provenances with inoculation

$(PS)_{qj}$ = the interaction effect of provenances with sterilisation

$(PMS)_{qij}$ = the interaction effect of provenances with sterilisation with inoculation.

3.2 Family trial

3.2.1 *Seeds*

Seeds were collected from Masese, Zambia (refer to provenance trial for location). Seed collection took place in August, 1995. Seeds were collected from eleven mature plus trees growing approximately 100 meters apart. On average, trees were about 15 meters in height. Seeds were fumigated with phosphene fumigant for five days and then stored dry in the cupboard under room temperature.

3.2.2 *Experimental design*

The study was carried out in the Faculty of Forestry nursery. A randomised complete block design with eleven treatments and ten replicates was used. A split plot design was used in fertiliser allocation. Six plants were used per treatment, per replicate giving a total of 660 plants in the experiment.

3.2.3 *Treatments*

All seeds were nicked at one end away from the embryo point using a surgical blade. Nicking enabled removal of part of the seed coat in order to enhance germination. Treatments consisted of eleven families and two levels of NPK granular fertiliser 3:2:1 (28) applied at zero and two grams per seedling. Half the number of seedlings per treatment received fertiliser. Fertiliser was applied when seedlings were four months old.

3.2.4 *Others*

Pot size, soil type, temperature, watering, chemical application and assessments were similar to the provenance trial.

3.2.5 *Statistical analysis*

Statistical Analysis System (SAS) programme, release 6.07 TS305 SAS institute Inc. (1989) was used for statistical analysis. Microsoft Excel Programme for windows 95, version 7.0a (1995) was used for the spread sheet, drawing of graphs and tables. Data for seed germination and leaf count were transformed as in the provenance trial. Seed mass and seed germination results were subjected to correlation analysis using Pearson Correlation Coefficients. The hypothesis that there was no correlation between seed mass and seed germination was tested at $\alpha=0.05$.

The ANOVA was based on the model:

Yield = Grand mean + block effect + family effect + residual

$$y_{ijk} = \mu + B_i + f_j + e_{ijk}$$

Where:

μ = underlying average yield for the whole set of units

B_i = effect of the i^{th} block

f_j = effect of the j^{th} family

e_{ijk} = residual effect

Effects were assumed to be additive. The random error terms were assumed to be normally distributed N(0, variance).

3.3 Vegetative propagation trial

3.3.1 *Source of cuttings*

Cuttings were collected from Mumbezi, Lualaba National Forest in Solwezi, Zambia (refer to the provenance experiment for description of the location). The forest in question was selectively logged for superior *P. angolensis* trees from 1987 to 89. Altogether, 300 cuttings were collected from saplings of about 2 m in height naturally regenerated from seeds. All branches from the saplings were removed and thrown away and only the stem was cut into two internodes. There was no specific length of the cuttings but each cutting had at least two internodes and that ensured the presence of buds in each cutting.

3.3.2 Handling and transportation of cuttings

Each 20 litre bucket of water was treated with three tea spoons of sugar and two tea spoons of boric acid 1%. Cuttings were put in these buckets with bottom ends facing down and transported to the station. In the field, cool boxes were used for storage of cuttings during the sorting out process.

3.3.3 *Experimental design*

The experiment took place in a glass house at the National Council for Scientific Research, Kitwe, Zambia. A randomised complete block design was used with three treatments and four replicates. Cuttings were planted at least 8 cm apart. Each treatment had 100 cuttings.

3.3.4 *Treatments*

Treatments were three mid diameter classes; 1 - 1.9 cm, 2 - 2.9 cm and 3 - 4.9 cm. Twenty grams of commercial rooting powder for hard woods (Seradix B No. 3) was dissolved in 500 millilitres tap water. One and a half centimetre of the bottom end of each cutting was dipped in the solution and immediately placed in the growing medium. Washed river sand from Samfya beach, Luapula province, Zambia was used as a growing medium.

3.3.5 *Assessments*

Assessments were carried out daily in the 1st week, once a week in the following days and then monthly. The experiment lasted for five months. Only above ground developments of

cuttings were recorded. After five months all cuttings which had never sprouted or had dead sprouts were physically checked for below ground developments.

3.3.6 *Growing conditions*

Cuttings were raised in a glass house with daily noon air temperatures averaging 30°C. No temperatures were taken for the growing medium. Watering of cuttings was done manually twice a day using a watering can. Cuttings were watered around 9.00 hours in the morning and around 16.00 hours in the afternoon. Interest to raise cuttings was there but the green house facilities and other resources for the experiment were not adequate

3.3.7 *Statistical analysis*

The study was descriptive therefore, no statistical analysis was done. Microsoft Excel Programme for windows 95, version 7.0a (1995) was used to summarise the data.

4. Results

Results on the performance of *P. angolensis* seedlings from four provenances and eleven families and the sprouting ability of *P. angolensis* cuttings are presented in this chapter. Significance levels for both provenance and family trial results were tested at α=0.05 using General Linear Model (GLM) procedures; means were separated using Duncan's multiple range test (SAS Inc., 1989). Provenance and family trial results for *P. angolensis* are summarised in Table 4.1.

Table 4.1. A summary of means for provenance and family trials of *P. angolensis.*

ASSESSMENT TYPE	PERIOD (DAYS)	PROVENANCE Mean	± SD	FAMILY Mean	± SD
Seed germination (number)	16	19.18	12.46		
Seed germination (number)	19			7.35	1.7
Height (cm)	49	3.91	1.44		
Height (cm)	105	4.22	1.42		
Height (cm)	217	4.52	1.38		
Height (cm)	38			4.5	1.09
Height (cm)	95			4.78	1.11
Height (cm)	245			4.71	1.01
Leaf count	49	4.23	1.22		
Leaf count	105	5.35	1.26		
Leaf count	38			4.5	0.72
Root collar diameter (cm)	217	1.78	0.63		
Root collar diameter (cm)	245			1.45	0.39
Above ground biomass(gm)	217	0.24	0.14		
Below ground biomass (gm)	217	0.71	0.47		
Above ground biomass(gm)	245			0.085	0.049
Below ground biomass(gm)	245			0.48	0.22
Seedling survival at last count:	217				
Masese provenance		81.5%			
Mufumbwe provenance		91.1%			
Chimanimani provenance		93.3%			
Solwezi provenance		94.8%			

4.1 Response of *P. angolensis* provenances to different soil treatments.

4.1.1 *Seed germination*

Seeds were sown on 12th March, 1997 and the first germination took place only after about 10 days from date of sowing the seed. Germination rate was initially slow in all treatments.

There were significant differences ($P < 0.05$) among provenances and between soil sterilisation treatments in number of germinated seeds. No significant differences ($P=0.8327$) were found between soil inoculation treatments in number of germinated seeds. There were no significant interaction effects ($P > 0.05$) for provenance x sterilisation, provenance x inoculation, sterilisation x inoculation and provenance x sterilisation x inoculation treatments (see ANOVA Table 1.1 in Appendix).

Chimanimani provenance had the highest number of mean germinated seeds of 86% within 14 days. These results came from soils which were not sterilised and not inoculated. Solwezi provenance produced the lowest number (42.5%) of mean germinated seeds from sterilised and not inoculated soils. Overall, Chimanimani provenance produced the highest number of mean germinated seeds from all soil treatments although there were no significant differences with Masese provenance. Solwezi provenance had the lowest mean germinated seeds from all soil treatments (Table 4.2 and Fig. 6).

Table 4.2. Seed germination count of *P. angolensis* from four provenances in response to soil treatments. Values for square root of number of germinated seeds were used. Four seeds per replicate were used.

	PROVENANCES				
SOIL TREATMENT	Chimanimani	Masese	Mufumbwe	Solwezi	Soil treatment means**
Sterilised and inoculated	1.77 a*	1.71 a	1.48 b	1.5 a	1.62 fg
Sterilised and not inoculated	1.74 a	1.72 a	1.52 ab	1.34 a	1.59 g
Not sterilised and inoculated	1.76 a	1.69 a	1.62 ab	1.46 a	1.64 fg
Not sterilised and not inoculated	1.85 a	1.7 a	1.70 a	1.47 a	1.69 f
Provenance means***	1.78 h	1.71 h	1.58 i	1.44 j	

** Means accompanied by the same letter (range a to b) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (f to g) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range h to j) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*

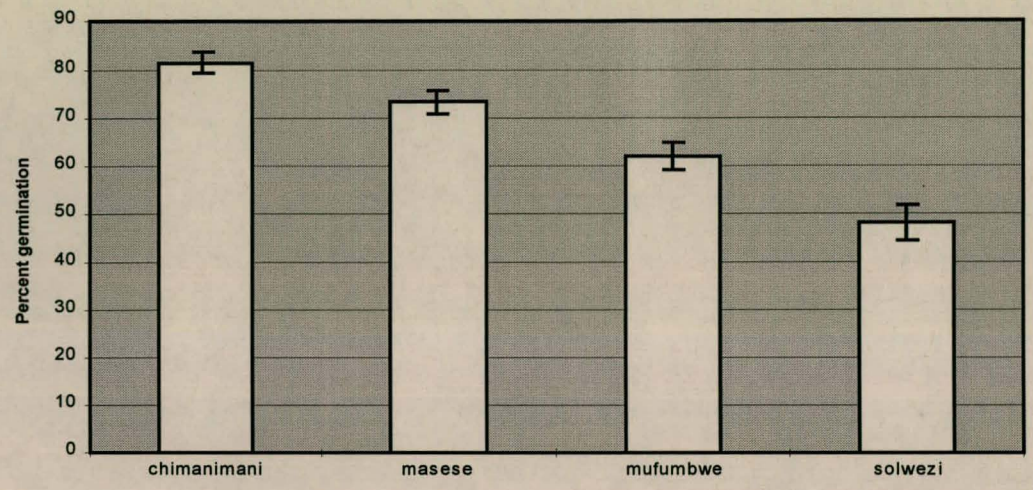


Fig. 6. Cumulative germination percentage of *P. angolensis* seeds from four provenances over a period of 16 days. Small vertical bars indicate standard deviation of the mean.

4.1.2. *Seed germination in relation to seed mass*

In all the four provenances, seed mass had no influence on number of germinated seed. Provenances with similar seed mass produced varying number of germinated seeds. For example, Solwezi, Masese and Mufumbwe provenances had no significant differences (P=0.05) in seed mass but their germination percentages varied considerably (Table 4.3 and Fig. 7).

Table 4.3. Variation in seed mass and cumulative germination percentage of *P. angolensis* from four provenances. Seed mass is for 320 seeds per provenance.

Provenance(name)	Seed mass (grams)	germination percentage
Chimanimani	70.14 a*	81.56
Mufumbwe	59.2 ab	62.19
Masese	58.66 ab	73.44
Solwezi	54.46 b	48.13

** Means accompanied by the same letter are not significantly different (P=0.05). Standard error (3.35).*

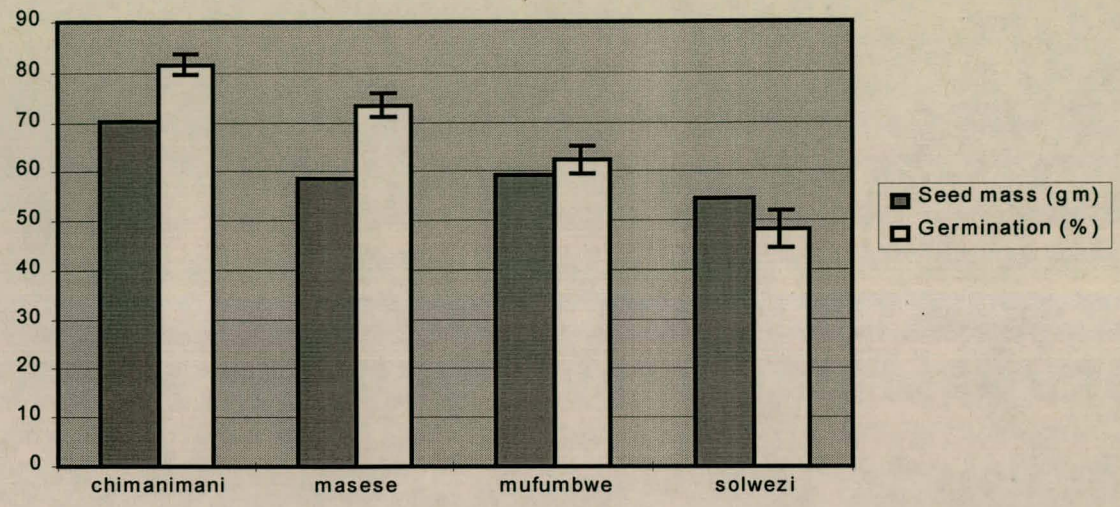


Fig. 7. Seed mass of each of the four provenances in relation to their seed germination percentage. Small vertical bars indicate standard deviation of the mean.

4.1.3. *Rate of seedling height growth*

Height measurements were taken at 49, 105 and 217 days after seeds were sown. Significant differences ($P < 0.05$) in seedling height growth were observed among replicates, provenances, and between soil sterilisation, and inoculation treatments from the first assessment at 49 days through to 217 days of seedling growth. During this period, no significant ($P > 0.05$) provenance x sterilisation, provenance x inoculation, sterilisation x inoculation and provenance x sterilisation x inoculation interaction effects were observed (ANOVA Tables 1.2, 1.3 and 1.4 in Appendix). From the interaction results obtained in this experiment, it seems factors under consideration acted independently of each other (Steel and Torrie, 1960).

Throughout the trial period, Mufumbwe provenance had the highest mean height growth. Solwezi provenance with initial poor performance managed to perform better than Chimanimani provenance by the time seedlings were 217 days old (Tables 4.4, 4.5 and 4.6 and Fig. 8).

From 49 days of seedling growth, soils which were not sterilised but inoculated out performed other soil treatments in all provenances in terms of seedling height growth except in Mufumbwe provenance where sterilised and inoculated soils did better. However, by the time

seedlings were 105 days up to 217 days, soils which were not sterilised and inoculated still performed better even in Mufumbwe provenance where it did not produce best height results previously (Tables 4.4, 4.5 and 4.6).

Table 4.4. Mean seedling heights (cm) of *P. angolensis* from four provenances at 49 days of growing.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	4.22 a*	4.02 a	4.48 a	3.53 a	4.07 ef
Sterilised and not inoculated	3.38 b	3.44 b	3.62 b	3.36 a	3.45 g
Not sterilised and inoculated	4.35 a	4.38 a	4.42 a	3.79 a	4.23 e
Not sterilised and not inoculated	3.67 b	3.95 a	4.25 a	3.62 a	3.88 f
Provenance mean***	3.91 q	3.94 q	4.19 p	3.58 r	

** Means accompanied by the same letter (range a to b) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range e to g) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range p to r) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*

Table 4.5. Mean seedling heights (cm) of *P. angolensis* from four provenances showing their response to soil treatments at 105 days of growing.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	4.17 a*	4.44 a	4.98 a	4.08 ba	4.42 h
Sterilised and not inoculated	3.45 b	3.67 b	4.06 b	3.74 b	3.73 j
Not sterilised and inoculated	4.36 a	4.45 a	5.15 a	4.45 a	4.61 h
Not sterilised and not inoculated	3.56 b	4.11 a	4.68 a	4.05 ba	4.11 i
Provenance mean***	3.90 g	4.16 f	4.72 e	4.09 fg	

** Means accompanied by the same letter (range a to b) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range h to j) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range e to g) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*

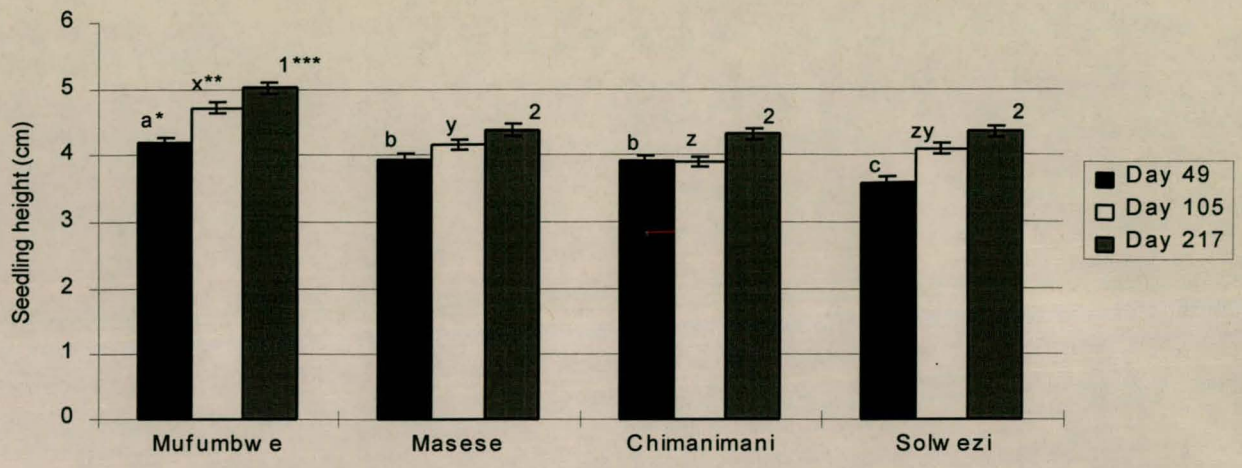
Table 4.6. Mean seedling heights (cm) of *P. angolensis* from four provenances at 217 days of growing.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	4.60 a*	4.51 a	5.30 ba	4.32 a	4.70 e
Sterilised and not inoculated	3.87 b	3.86 b	4.38 c	4.18 a	4.07 g
Not sterilised and inoculated	4.75 a	4.59 a	5.48 a	4.68 a	4.87 e
Not sterilised and not inoculated	4.03 b	4.56 a	4.90 b	4.20 a	4.43 f
Provenance mean***	4.32 n	4.38 n	5.03 m	4.35 n	

** Means accompanied by the same letter (range a to c) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range e to g) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range m to n) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*



** Bars accompanied by the same letter (range a to c) are not significantly different from each other at (P=0.05)*

*** Bars accompanied by the same letter (range x to z) are not significantly different from each other at (P=0.05)*

**** Bars accompanied by the same number are not significantly different from each other at (P=0.05).*

Fig. 8. Mean seedling height (cm) growth of *P. angolensis* from four provenances at 49, 105 and 217 days of growing. Small vertical bars indicate standard error of the mean.

4.1.4 *Effect of soil sterilisation and inoculation on seedling height growth*

Soils which were sterilised and not inoculated had lowest mean seedling heights in all provenances from time of seed germination through to 217 days of seedling growth. A treatment combination of soil sterilisation and inoculation managed to give second best results throughout the trial period. By the time seedlings were 217 days old, no significant differences were observed between soils which were not sterilised but inoculated and a combination of soil sterilisation and inoculation treatment (Table 4.6). It appears soil inoculation on its own had a significant effect on seedling height growth while soil sterilisation did not. Soils which were inoculated and not sterilised had better growth rates throughout the trial period (Tables 4.7, 4.8 and 4.9).

Table 4.7. Effect of soil sterilisation and soil inoculation on height (cm) growth of *P. angolansis* seedlings at 49 days of seedling growth.

		STERILISATION		
		NO	YES	MEAN
INOCULATION	NO	3.89	3.45	3.67
	YES	4.23	4.07	4.15
	MEAN	4.06	3.76	

Table 4.8. Effect of soil sterilisation and soil inoculation on height (cm) growth of *P. angolensis* seedlings at 105 day .

		STERILISATION		
		NO	YES	MEAN
INOCULATION	NO	4.11	3.73	3.92
	YES	4.61	4.42	4.52
	MEAN	4.36	4.01	

Table 4.9. Effect of soil sterilisation and soil inoculation on height (cm) growth of *P. angolensis* seedlings at 217 days of seedling growth.

		STERILISATION		
		NO	YES	MEAN
INOCULATION	NO	4.43	4.07	4.25
	YES	4.87	4.70	4.75
	MEAN	4.65	4.35	

4.1.5 *Root collar diameter assessment*

There were significant differences (P=0.0001) in root collar diameter sizes among the four provenances and between soil sterilisation and inoculation treatments. Provenance x inoculation interactions (P=0.0138) were observed (See Table 1.5 in Appendix).

There were no significant differences between Mufumbwe and Solwezi provenances in diameter size although Mufumbwe provenance produced the largest diameter size from all the provenances tried. Chimanimani provenance had the smallest root collar diameter size (Table 4.10).

There was a significant effect from combining soil sterilisation and inoculation treatments. This combination produced the largest root collar diameter size. Soils which were not sterilised and not inoculated had the lowest diameter size. Soil inoculation on its own managed to perform better than soil sterilisation on its own (Table 4.10 and 4.11).

Table 4.10. Mean seedling root collar diameter (cm) growth of *P. angolensis* from four provenances at 217 days.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	1.81 a*	1.75 a	2.14 a	2.00 a	1.92 e
Sterilised and not inoculated	1.48 cb	1.86 a	1.85 b	1.97 a	1.78 f
Not sterilised and inoculated	1.59 b	1.68 a	2.05 a	1.85 ba	1.8 f
Not sterilised and not inoculated	1.38 c	1.59 a	1.72 b	1.68 b	1.6 g
Provenance mean***	1.58 r	1.72 q	1.94 p	1.87 p	

** Means accompanied by the same letter (range a to c) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range e to g) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range p to r) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*

Table 4.11. Effect of soil sterilisation and soil inoculation on diameter (cm) growth of *P. angolensis* seedlings at 217 days.

		STERILISATION		
		NO	YES	MEAN
INOCULATION	NO	1.60	1.78	1.69
	YES	1.80	1.92	1.86
	MEAN	1.70	1.85	

4.1.6 *Above ground biomass yield*

Significant differences (P=0.0001) were observed among provenances, and between soil sterilisation and soil inoculation treatments. Replication effects (P=0.0093) were also observed. There were provenance x inoculation interactions (P=0.0145) in above ground biomass production (See ANOVA Table 1.6 in Appendix). Seedlings produced more below ground biomass than above ground biomass (Fig. 9)

Chimanimani provenance produced highest above ground biomass yield and Masese provenance had lowest (Table 4.12). Soils which were sterilised and inoculated produced higher above ground biomass yield than other soil treatments. Unsterilised and uninoculated soils had lowest biomass yield (Table 4.13).

Table 4.12. Mean seedling above ground biomass production (grams) of *P. angolensis* from four provenances at 217 days of growing.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	0.42 a*	0.19 a	0.03 a	0.24 a	0.29 e
Sterilised and not inoculated	0.27 bc	0.15 ba	0.28 a	0.22 ba	0.23 f
Not sterilised and inoculated	0.34 ba	0.14 b	0.29 a	0.26 a	0.26 fe
Not sterilised and not inoculated	0.19 c	0.09 c	0.20 b	0.15 b	0.16 g
Provenance mean***	0.30 p	0.14 r	0.27 p	0.22 q	

** Means accompanied by the same letter (range a to c) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range e to g) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range p to r) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*

Table 4.13. Effect of soil sterilisation and soil inoculation on above ground biomass yield in grams at 217 days of seedling growth.

		STERILISATION		
		NO	YES	MEAN
INOCULATION	NO	0.16	0.23	0.2
	YES	0.26	0.29	0.28
	MEAN	0.21	0.26	

4.1.7 *Below ground biomass yield*

Significant differences (P<0.05) in terms of below ground biomass production were observed in soil inoculation treatments, replications and provenances. There were no significant differences (P=0.7216) between soil sterilisation treatments. There were interaction effects for provenance x inoculation combinations (See Table 1.7 in Appendix).

Soils which were not sterilised but inoculated produced highest below ground biomass yield. Of all soil treatments, sterilised but not inoculated soils produced the lowest biomass yield (Tables 4.14 and 4.15).

Table 4.14. Mean seedling below ground biomass production (grams) of *P. angolensis* from four provenances at 217 days of growing.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	1.19 a*	0.69 a	0.8 b	0.71 a	0.85 e
Sterilised and not inoculated	0.70 b	0.42 b	0.53 c	0.49 bc	0.54 f
Not sterilised and inoculated	1.21 a	0.56 ba	1.06 a	0.65 ba	0.87 e
Not sterilised and not inoculated	0.61 b	0.38 b	0.58 cb	0.39 c	0.49 f
Provenance mean***	0.92 p	0.52 r	0.74 q	0.56 r	

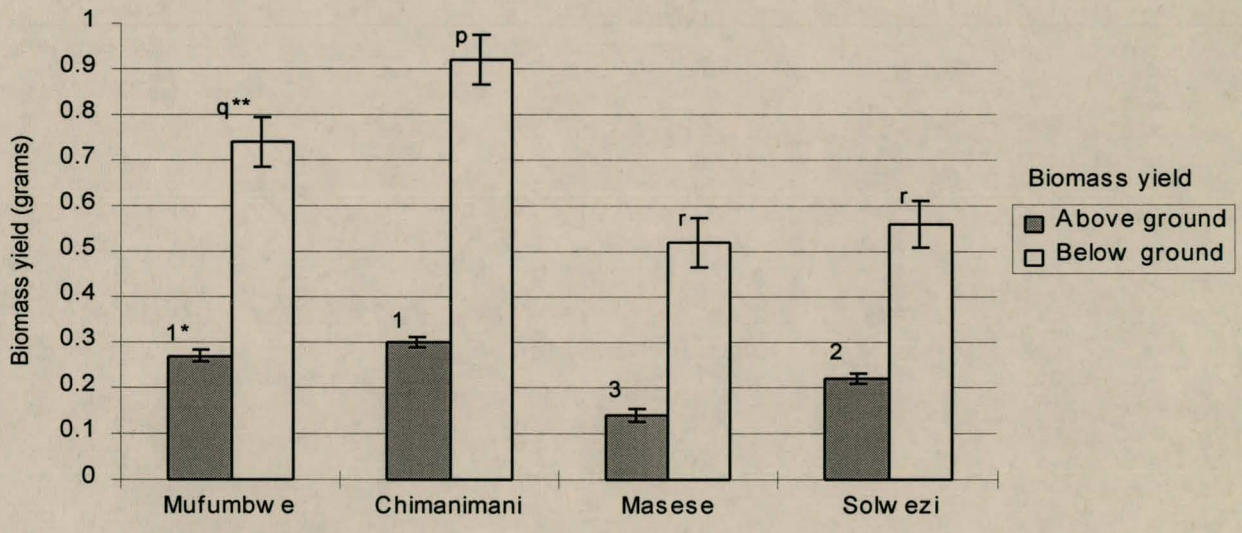
** Means accompanied by the same letter (range a to c) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range e to f) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range p to r) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*

Table 4.15. Effect of soil sterilisation and soil inoculation on below ground biomass yield of *P. angolensis* seedlings at 217 days of seedling growth.

		STERILISATION		
		NO	YES	MEAN
INOCULATION	NO	0.49	0.54	0.51
	YES	0.87	0.85	0.86
	MEAN	0.68	0.69	



**Means followed by the same number are not significantly different (P=0.05)*

***Means followed by the same letter are not significantly different (P=0.05).*

Fig. 9. Mean above and below ground dry biomass yield (grams) of *P. angolensis* from four provenances. Small vertical bars indicate standard error of the mean.

4.1.8 *Total leaf production*

By 49 days, significant differences ($P < 0.05$) among provenances and between soil inoculation treatments in terms of leaf production were observed. However, there were no significant differences between soil sterilisation treatments (Table 4.16). By 105 days, apart from significant differences observed earlier on, there were also significant differences ($\alpha=0.05$) which had occurred between soil sterilisation treatments (Table 4.17). At 49 days there were significant provenance x sterilisation interactions and significant provenance x sterilisation x inoculation interactions for leaf production but at 105 days the interaction provenance and sterilisation disappeared; the 3-way interaction remained (ANOVA Tables 1.8 and 1.9 in Appendix).

Mufumbwe provenance had the highest number of total leaves by 49 days. Solwezi and Masese provenances had by then the lowest mean total leaf production. By 105 days, Solwezi managed to produce more total leaves than Masese provenance. By 105 days, Masese provenance became the lowest in terms of leaf production (Fig. 10).

Table 4.16. Mean seedling leaf count of *P. angolenis* from four provenances at 49 days using transformed data.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	3.06 ba*	3.04 a	3.22 a	2.93 ba	3.06 h
Sterilised and not inoculated	3.01 b	2.88 b	3.09 b	2.95 ba	2.98 l
Not sterilised and inoculated	3.12 a	2.98 a	3.27 a	3.0 a	3.09 h
Not sterilised and not inoculated	3.02 ba	2.87 b	3.21 a	2.86 b	2.99 i
Provenance mean***	3.19 f	2.94 g	3.2 e	2.94 g	

** Means accompanied by the same letter (range a to b) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range h to I) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range e to g) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*

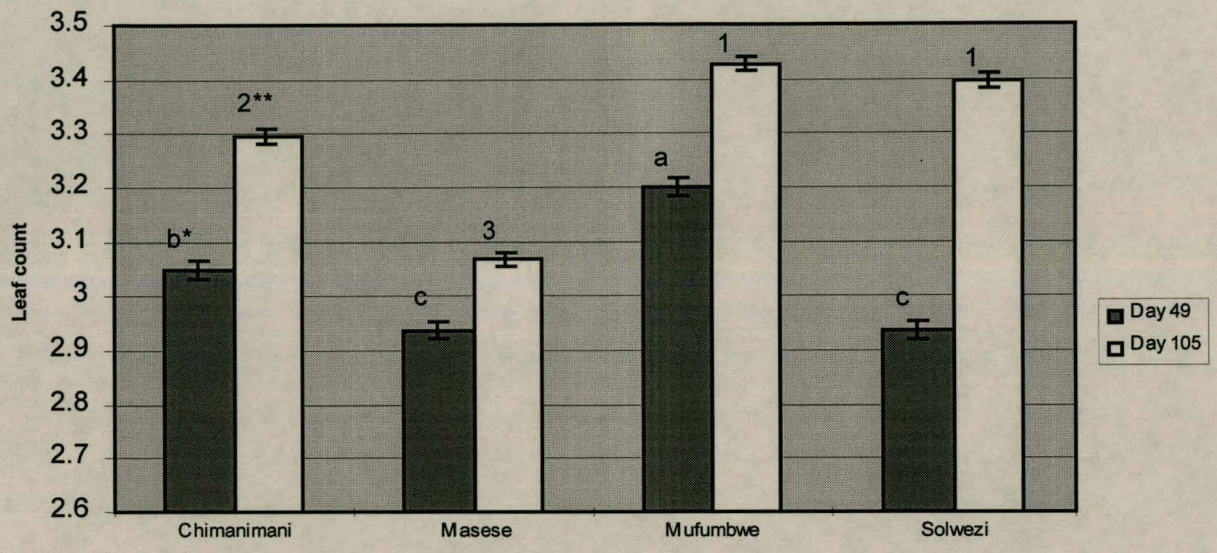
Table 4.17. Mean seedling leaf count of *P. angolensis* from four provenances at 15 weeks of growing.

SOIL TREATMENT	PROVENANCE				Soil treatment means**
	Chimanimani	Masese	Mufumbwe	Solwezi	
Sterilised and inoculated	3.29 ba*	3.15 a	3.46 a	3.42 ba	3.33 e
Sterilised and not inoculated	3.28 ba	2.98 c	3.33 b	3.36 b	3.23 g
Not sterilised and inoculated	3.35 a	3.11 ba	3.47 a	3.45 a	3.35 e
Not sterilised and not inoculated	3.25 b	3.04 bc	3.45 a	3.35 b	3.28 f
Provenance mean***	3.3 i	3.07 j	3.43 h	3.4 h	

** Means accompanied by the same letter (range a to c) are not significantly different when comparing four soil treatments within each provenance (P=0.05)*

*** Means accompanied by the same letter (range e to g) are not significantly different when comparing the four soil treatments grouped over provenances (P=0.05)*

****Means accompanied by the same letter (range h to j) are not significantly different when comparing provenances and ignoring soil treatments (P=0.05).*



** Means accompanied by the same letter are not significantly different (P=0.05)*

*** Means accompanied by the same number are not significantly different (P=0.05).*

Fig. 10. Mean seedling leaf production of the four provenances at 49 and 105 days of seedling growth. Small vertical bars indicate standard error of the mean.

4.1.9 *Seedling survival*

Quite a number of seedlings in all provenances had died by the time seedlings were 217 days old. However, there were no significant differences (P=0.05) in number of dead seedlings in the all provenances (Table 4.18).

Table 4.18. Mortality rate of seedlings per provenance at 217 days old.

Provenance(name)	Mortality percentage
Masese	18.5 a*
Mufumbwe	8.9 ab
Chimanimani	6.69 ab
Solwezi	5.2 b

** Means accompanied by the same letter are not significantly different (P=0.05). Standard error (3.6).*

4.2 Differences in seedling growth of eleven families of *P. angolensis* from Masese provenance.

4.2.1 *Seed germination*

Seeds were sown on 26-02-97. The first seed germination took place by the 5th day. By the 19th day of sowing, most families had stopped germinating.

There were significant differences (P = 0.0001) observed among families in terms of number of germinated seeds (Table 4.19 and ANOVA Tables 2.1 in Appendix). Family 9 performed far better than other families producing 91% of seed germination results followed by family 6 with a germination of 89%. Germination results from families 9 and 6 were however, not statistically significant. Family 11 had the lowest germination percentage of 52% (Fig. 11 and Table 4.19). Most of the ungerminated seeds in all families were rotten in the soil.

Table 4.19. Mean number of germinated seeds from a sample of 10 seeds per replicate per family using transformed data.

Family No.	Mean number of germinated seed	Duncan grouping
9	3.01	a*
6	2.97	ab
4	2.84	abc
3	2.74	bcd
7	2.73	bcd
8	2.73	bcd
5	2.65	cd
10	2.60	cd
2	2.58	cd
1	2.50	d
11	2.26	d

**Based on Duncan's multiple range test, means with the same letter are not significantly different (P=0.05).*

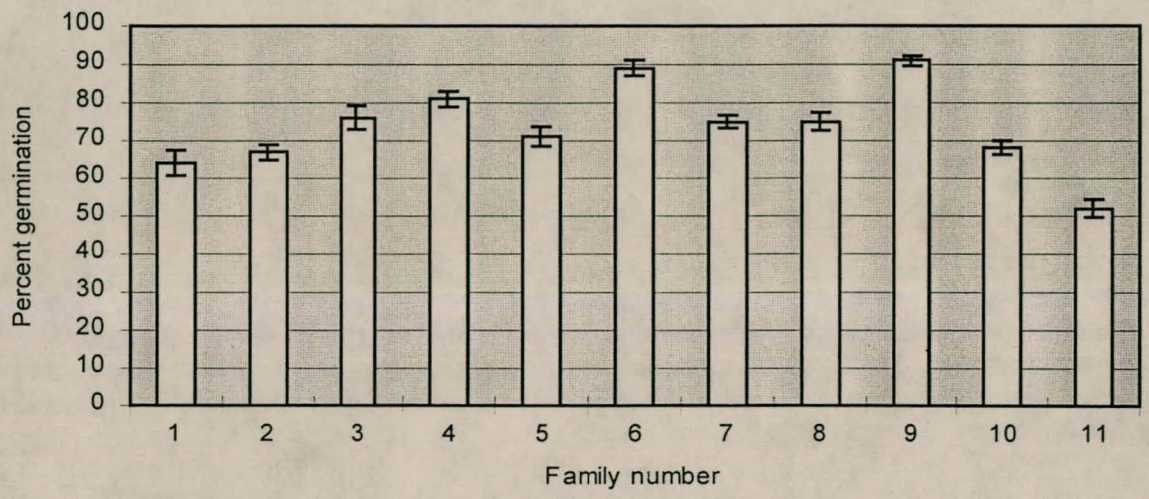


Fig. 11. Mean germination percentage of seeds from eleven families of *P. angolensis*. Small vertical bars indicate standard deviation of the mean.

4.2.2 *Seed germination in relation to seed mass*

Seed germination varied from family to family regardless of the amount of seed mass in each family (Fig. 12). There was no significant correlation (P=0.05) between seed mass and seed germination in all the eleven families (Fig. 13).

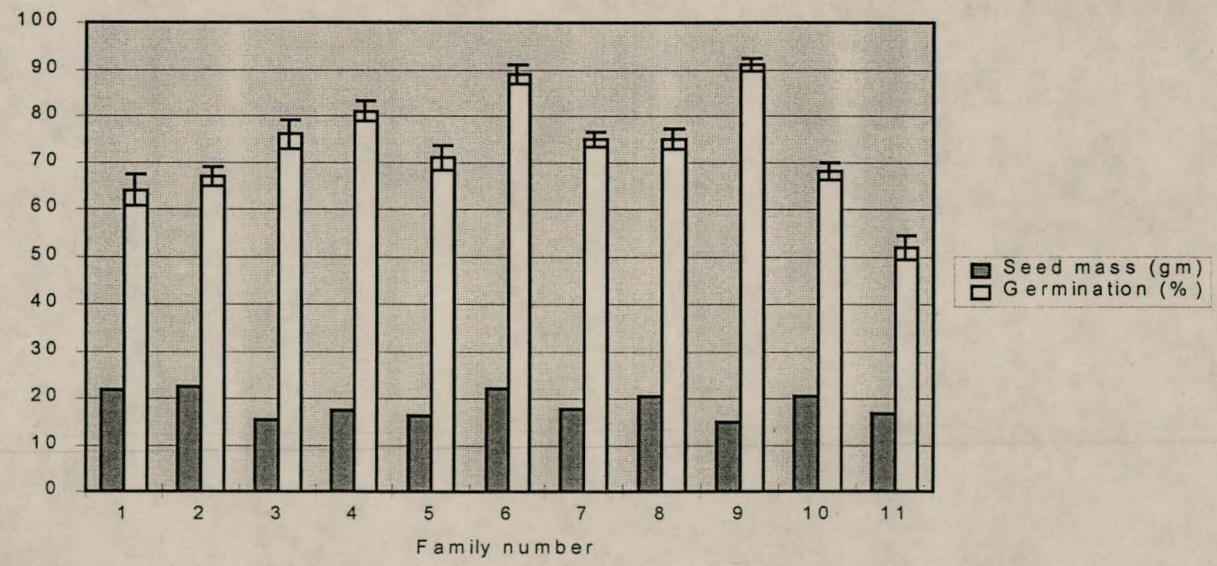


Fig. 12. Variation in seed mass and cumulative germination percentage for 11 families from Masese provenance. Seed mass are for 114 seeds per family. Small vertical bars indicate standard deviation of the mean.

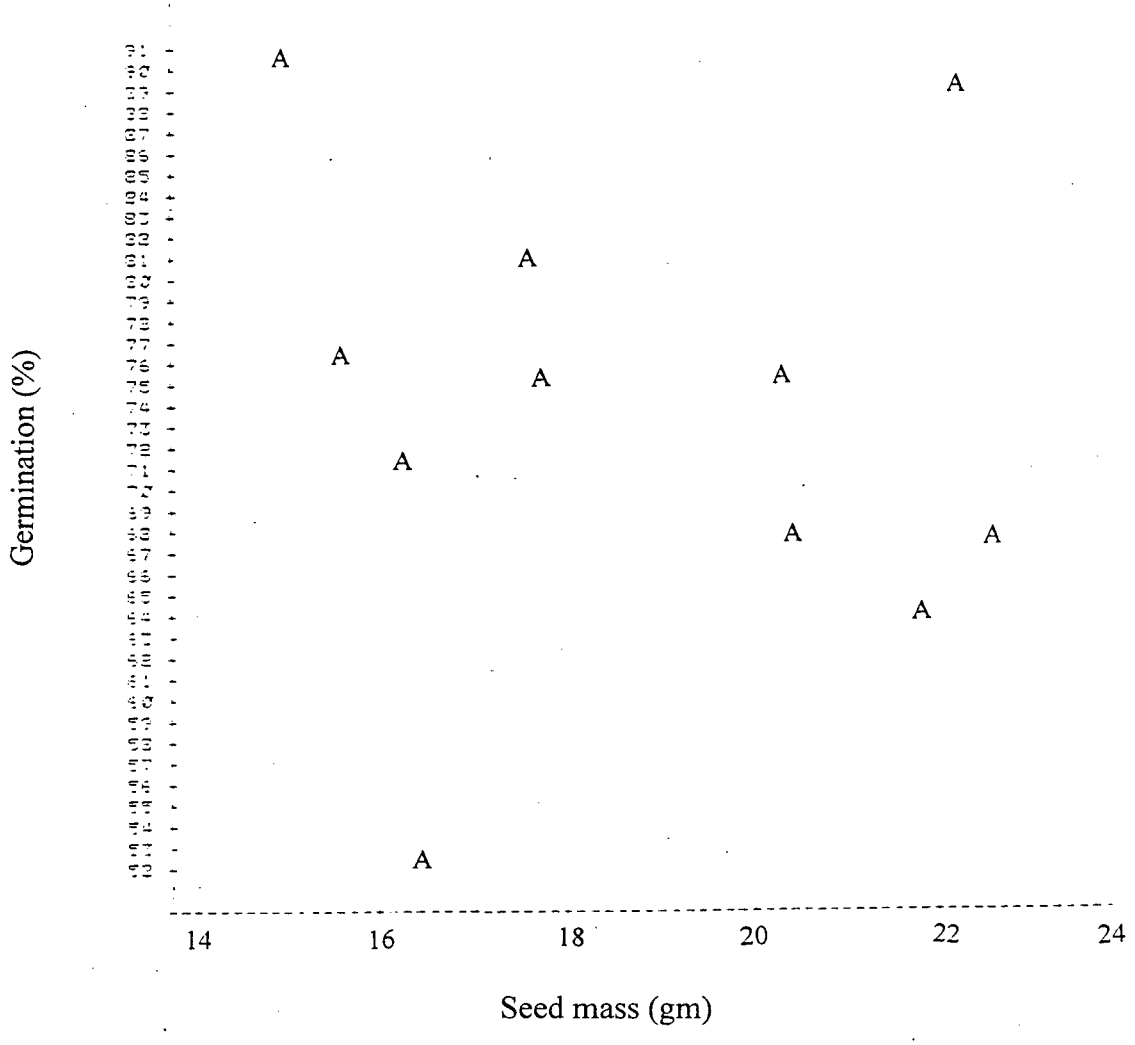


Fig. 13. Plot of seed mass in relation to germination percentage of *P. angolensis* seeds from eleven families.

4.2.3 *Rate of seedling height growth*

Significant differences (P=0.0001) in height growth were observed among *P. angolensis* families from Masese provenance by 38, 95 and 245 days from date of sowing (ANOVA Tables 2.2, 2.3 and 2.4 in the Appendix).

At 38 days, family 8 performed best in height growth rate followed by family 2 although, there were no significant differences between the two families. Families 7 and 11 had the lowest growth rate by the time seedlings were 38 days old (Table 4.20). Families 8 and 2 still continued to have the highest seedling height growth rates up to the time seedlings were 95 days old. By this time, family 7 managed to perform better than family 11 and therefore, family 11 still remained the poorest (Table 4.21). After the die-back period (in winter) many families had their mean seedling heights dropped. However, families 8, 2, 9, 6 and 4 still maintained their high yielding heights. Family 7 had a big drop in height growth (Table 4.22).

Table 4.20. Seedling heights (cm) for the 11 families by 38 days of growing.

Family No.	Number of seedlings	Mean height (cm)	Duncan grouping
8	60	5.3683	a*
2	60	5.0695	ab
9	60	4.9467	b
6	60	4.8617	bc
4	60	4.5667	cd
5	60	4.555	cd
3	60	4.3633	d
10	60	4.2583	d
1	60	4.2117	de
7	60	3.8667	ef
11	55	3.6455	f

**Based on Duncan's multiple range test means with the same letter are not significantly different (P=0.05).*

Table 4.21. Seedling mean heights (cm) for the 11 families by 95 days of growing.

Family No.	Number of seedlings	Mean height (cm)	Duncan grouping
8	60	5.635	a*
2	60	5.305	ab
9	60	5.2283	b
6	60	5.0567	bc
5	60	4.935	bcd
4	60	4.7533	ecd
10	60	4.6283	efd
7	60	4.4867	ef
3	60	4.4067	ef
1	60	4.3083	f
11	55	3.7309	g

**Based on Duncan's multiple range test, means with the same letter are not significantly different (P=0.05).*

Table 4.22. Seedling mean heights (cm) for the 11 families of *P. angolensis* by 245 days of growing.

Family No.	Number of seedlings	Mean height (cm)	Duncan grouping
8	24	5.4583	a
2	23	5.4	a
9	27	5.0222	ba
6	21	4.7524	bc
4	25	4.72	bc
5	29	4.6138	bc
1	22	4.4773	bcd
11	19	4.4474	bcd
10	24	4.4417	bcd
3	27	4.3963	cd
7	24	4	d

**Based on Duncan's multiple range test, means with the same letter are not significantly different (P=0.05).*

4.2.4 *Diameter growth of P. angolensis families*

Significant differences (P<0.05) were observed between families in terms of diameter growth (See ANOVA Table 2.5 in Appendix). Family 1 had better diameter growth than other families. Generally, differences in diameter growth were not big in all families (Table 4.23).

Table 4.23. Diameter growth of *P. angolensis* seedlings at 245 days.

Family No.	Number of seedlings	Mean height (cm)	Duncan grouping
1	21	1.6733	a
8	24	1.5700	ba
5	29	1.5500	bac
4	25	1.5236	bac
11	19	1.4774	bac
6	21	1.4576	bac
10	24	1.3763	bc
3	27	1.3678	bc
7	24	1.3567	bc
9	27	1.3204	bc
2	23	1.3026	c

**Based on Duncan's multiple range test, means with the same letter are not significantly different (P=0.05).*

4.2.5 *Total leaf production*

There were significant differences (P=0.0001) among families in total leaf production (ANOVA Table 2.6 in Appendix). Family 8 had the highest number of total leaf production followed by family 6. Family 11 had recorded the lowest total leaf production (Table 4.24).

Table 4.24. Mean total leaf production per family at 38 days.

Family No.	Number of seedlings	Mean height (cm)	Duncan grouping
8	60	3.22647	a*
6	60	3.17781	ab
10	60	3.15165	cb
1	60	3.14694	cb
2	59	3.1245	bcd
3	60	3.11017	ecd
5	60	3.08172	ed
9	60	3.07475	ed
7	60	3.07354	ed
4	60	3.05707	ed
11	55	3.05486	e

**Based on Duncan's multiple range test means accompanied by the same letter are not significantly different (P=0.05).*

Table 4.25. Above ground biomass production at 245 days of seedling growth.

Family No.	Number of seedlings	Mean dry shoot mass (grams)	Duncan grouping
4	19	0.10684	a*
10	19	0.10316	ab
8	18	0.09500	abc
11	14	0.09071	abc
2	15	0.08667	abc
6	19	0.08526	ebc
1	20	0.08450	abc
3	16	0.07875	abc
5	20	0.07550	abc
9	18	0.06722	bc
7	17	0.06000	c

**Based on Duncan's multiple range test means accompanied by the same letter are not significantly different (P=0.05).*

4.2.6 *Above and below ground biomass production*

There were significant differences (P=0.0241) and (P=0.0015) between families in above and below ground biomass production respectively at 245 days of growing (See ANOVA Tables 2.7 and 2.8 in Appendix). Most of the seedlings had shed their leaves and the above ground biomass consisted of stems. Seedlings had produced more below ground biomass than above ground biomass (Tables 4.25 and 4.26). There was correlation between height and above ground biomass (r=0.18721). There was no correlation between height and below ground biomass (r = -0.06242) (Table 2.9 in Appendix).

Table 4.26. Below ground biomass production at 245 days of seedling growth.

Family No.	Number of seedlings	Mean dry root mass (grams)	Duncan grouping
8	18	0.60167	a
6	19	0.55632	ab
10	19	0.50474	ab
4	19	0.49684	ab
11	14	0.47857	ab
7	17	0.46765	ab
5	20	0.45750	ab
1	20	0.43450	b
9	18	0.42722	b
3	17	0.42647	b
2	15	0.42467	b

**Based on Duncan's multiple range test means accompanied by the same letter are not significantly different (P=0.05).*

4.3 Vegetative propagation trial results

The number of cuttings which produced shoots were counted as shown in Table 4.27. The last count was done after 3 months and 2 weeks (104 days) of running the experiment. All results are shown in Table 4.27, Figures 14 and 15.

Table 4.27. Percentage of cuttings that produced shoots with time.

	TIME IN DAYS				
Diameter class (cm)	day 4	day 7	day 30	day 81	day 104
1 - 1.9	49	61	50	0	0
2 - 2.9	74	89	84	1	0
3 - 4.9	77	85	87	17	10

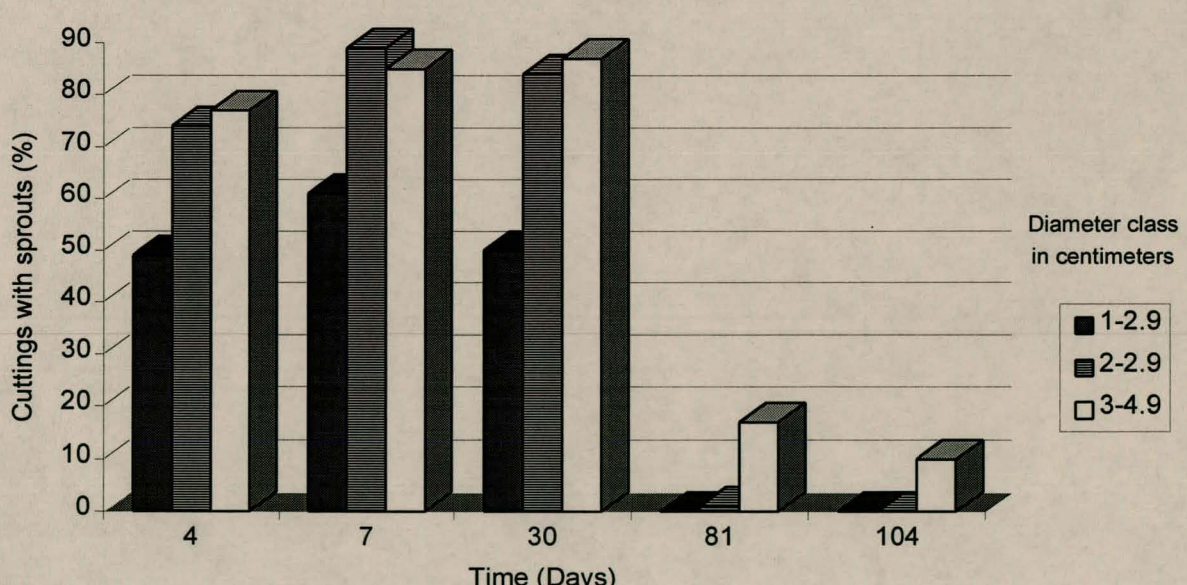


Fig. 14. Progressive performance of cuttings that produced shoots with time.

Observations were done on the rate of shoot production and shoot death in the following diameter classes; 1 - 1.9, 2 - 2.9 and 3 - 4.9 cm. From time of insertion of cuttings in the growing medium, the rate of shoot production started off by increasing steadily in all diameter classes investigated until after the 7th day when sprouting stopped especially in cuttings with less than 2.9 cm mid-diameter. After this period, sprouts started wilting and dying. Cuttings with mid-diameter class 3 - 4.9 cm were the only ones which continued sprouting until the 30th day and thereafter, shoots started dying (Table 4.27 and Fig. 14). By the time it was 81 days, cuttings with diameter class 1 - 1.9 cm had all the sprouts dead and those with diameter class 2 - 2.9 cm had only 1 cutting with sprouts. By then, diameter class 3 - 4.9 cm had 17% of cuttings with sprouts still alive. By the time it was 104 days, cuttings with diameter class 3 - 4.9 cm had some sprouts dead and had remained with only 10% of cuttings with sprouts (Table 4.27 and Fig. 14). All cuttings with dead shoots had no roots formed.

A count of cuttings which never produced sprouts from date of planting to 104 days was also done. Cuttings with mid-diameter class 1 - 1.9 cm had the highest number followed by 2 - 2.9 and then 3 - 4.9 cm (Fig. 15). No sign of root development was observed in the unsprouted cuttings.

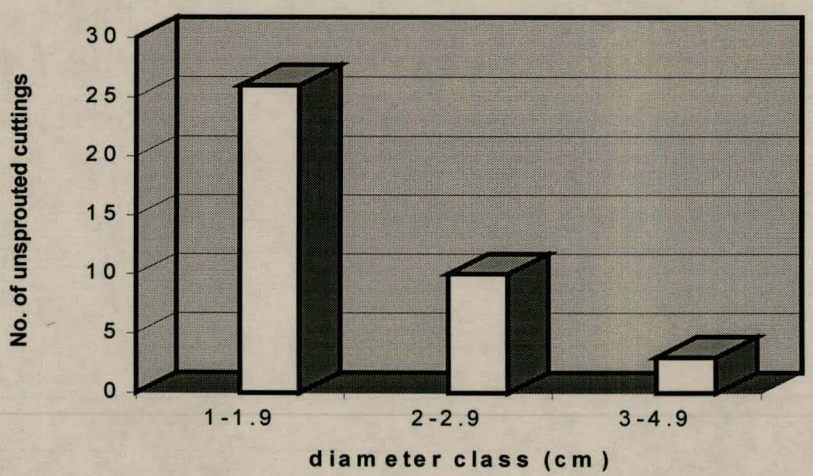


Fig. 15. Number of cuttings without sprouts from beginning of the experiment to day 104.

5. DISCUSSION

5.1 Family and provenance trials

In the provenance trial, provenances and soil sterilisation treatments used showed significant differences ($P < 0.05$) in seed germination percentage. Inoculation of the soil with mycorrhizal fungi had no effect on seed germination percentage. The results of the inoculum not having any effect on seed germination were expected as mycorrhizal fungi are only in symbiosis with plants through feeder roots or short roots. According to Menge and Timmer (1982) the effect of mycorrhizal infection depends on among other factors, where the inoculum is placed and whether the seedling will get in contact.

Looking at the mean number of germinated seed per provenance and family, it appears that seed mass had no influence on seed germination percentage. These results were supported by the correlation analysis done on the eleven families from Masese provenance. The correlation results indicated no significant relationship ($r = -0.14091$; $P = 0.6794$) between seed mass and seed germination. In this trial, the highest mean germination percentage was from family 9 with the lightest seed mass. Some families for example, 10, 2 and 1, had heavier seeds but their mean germination percent was lower than in light mass seeds (Fig. 12). Lack of influence of seed mass on seed germination was further confirmed in the trial of four provenances where Masese and Mufumbwe provenances with lighter seeds had no significant difference in germination percentage when compared with Chimanimani provenance with heavier seeds (Table 4.3). Marunda (1993) found similar results from *Acacia nilotica, Faidherbia albida* and *Azadirachta indica* seeds of having no variation in germination time and percentage against seed mass. Apparently, there are other potential factors other than seed mass that control seed dormancy and germination. Some of the factors are soil moisture and nitrate content, the year when seed was collected and the location of the fruit on the tree (Angosto Trillo and Matilla Carro, 1993). Seed physiological quality has also got an influence on germination (Souza and Marcos-Filho, 1993). The genetic make up that exists between individual trees and different seed sources might also have contributed to variations in the rate of seed germination in the four provenances and the eleven families under study.

In the provenance study, soils which were not sterilised but inoculated produced higher height growth rates and higher below ground biomass yield by the time seedlings were 49 and 217

days old respectively. Below ground biomass yield variations were quite high between soils which were inoculated and not inoculated regardless of soil sterilisation treatment. Soil sterilisation did not seem to have much effect on seedling growth. These results showed the effect and potential of soil inoculation on its own in enhancing height and biomass production. Soils which were not sterilised and not inoculated had the lowest below ground biomass yield (Table 4.15). Under normal circumstances, better height growth and below ground biomass yields were expected from a soil treatment combination of sterilisation and inoculation. Soil sterilisation was expected to facilitate the introduced inoculum to easily establish without facing any competition from the host micro-organisms if any. On the other hand, soil inoculation was expected to aid in improving plant growth by enhancing acquisition of mobile and immobile elements such as sulphur, calcium and potassium (Bowen and Nambiar, 1984 and Theron, 1991). Soil inoculation was also expected to deter root pathogens, decrease soil toxicity and increase plant resistance to drought if any (Carlson, 1994; Brown and Bledsoe, 1996).

Many researchers have reported significant responses in seedling height and diameter growth rate, increased below and above ground biomass yield from a combination of soil sterilisation and soil inoculation treatments. Donald (1976) for example reported significant growth response of *Pinus radiata* to soil sterilisation and soil inoculation with *Rhizopogon luteolus* at Stellenbosch nursery. Marx *et al.* (1977) obtained a growth increase of 125% in *P. taeda* in inoculated and fumigated soils. Theodorou (1967) discovered soils sterilised with steam and inoculated with *R. luteolus* fungi having 17 - 31% mycorrhizal fungi infection compared to 16% in the non-sterilised and non-inoculated soils. In the current study, it is possible that some other factors might have negatively influenced the plant response to a treatment combination of soil sterilisation and inoculation. According to Donald (1981), Little and Maun (1996) there is a possibility of soil sterilisation killing not only harmful resident micro-organisms, but also beneficial ones to plant growth. It is also possible that *Pterocarpus angolensis* seedlings might have required more than the introduced mycorrhizal fungi for better growth. Shepherd (1986) reported on most tree species requiring several associations present for successful growth and development.

Apart from the above-mentioned factors, there could have been other reasons that attributed to poor performance of seedlings in terms of height and below ground biomass growth in soils which were sterilised and inoculated. Other factors to consider are that during soil

sterilisation not all targeted soil micro-organisms are killed. According to Danielson and Davey (1969), Marx *et al.* (1970), Ridge and Theodorou (1972) there is also a possibility of rapid recolonisation by surrounding soil microflora and undesirable fungi of soil previously sterilised. An example of *Thelephora terrestris* being efficient at colonising fumigated or sterilised soils of *Pinus elliottii* and *P. patula* is given by Reliham and Laing (1996). In another experiment in the southern United States, Ridge and Theodorou (1972) also discovered at least five culturally different ectomycorrhizal fungi of *P. echinata* which had colonised fumigated soil within nine months in the green house. In another study, the presence of bacteria colonies on *Glomus* hyphae growing on soy bean roots in previously sterilised soils were reported by Ross and Daniels (1982). These micro-organisms that recolonise fumigated or sterilised soil could be either beneficial, antagonistic or parasitic and may negatively affect plant growth. In all, seedling growth responses depend on how rapid infection and colonisation of host roots by mycorrhizal fungi takes place and how superior the introduced mycorrhizal fungi is to the indigenous strain or the recolonisers. According to Swart and Theron (1990) competition between soil organisms could have a direct influence on the persistence of any introduced mycorrhizal fungi.

In this study, a treatment combination of soil sterilisation and inoculation only managed to produce seedling height growth results not significantly different from a treatment combination of unsterilised and inoculated soils by the time seedlings were 217 days old. Soil sterilisation and inoculation had however, lower results (Tables 4.6 to 4.9). Hodgson (1979) also reported on this possibility. From this experiment, it would appear soil sterilisation unlike soil inoculation requires some time in order to be effective and appreciated.

Significant differences were noted in mortality rate of seedlings in all provenances under study. Although seedling death rates ranged from 5.2 to 18.5% in the four provenances, no investigations were done on the cause. However, *Pterocarpus angolensis* seedlings/trees are known to suffer from the wilting disease (*Fusarium oxysporum*) which causes plants to die whether under nursery or field conditions. The wilting problem has been reported in Zambia and western Zimbabwe (Van Wyk *et al.*, 1993).

Almost all roots sampled from the provenance and family trials showed signs of lateral root growth dormancy. A demarcation between fresh growth on root tips and old parts of lateral root was evidently seen during sampling in summer (November, 1997). It would appear that

during die-back period, the genus *Pterocarpus* does not only stop growing above ground but also below ground especially lateral roots and root hairs. This may explain why the tap root is so thick as it appears to be the only one that continues to grow even under harsh growing conditions.

In this study, the genus *Pterocarpus* from a wide geographical distribution varied in growth when planted together under similar controlled environmental conditions. The rate of seedling height, diameter and biomass growth varied considerably from provenance to provenance and within provenances (Tables 4.12 and 4.14). The variations in seedling height growth and biomass production, in the four provenances, under study were observed as early as 49 and 217 days of seedling growth respectively. Mufumbwe provenance was the most vigorous in height, root collar diameter and was second in above and below ground biomass growth. It also continued to produce higher mean heights from date of sowing to 217 days of seedling growth. It was possible for Mufumbwe provenance to have performed better in height growth due to its high production of above ground biomass. The above ground biomass is responsible for photosynthesis which is essential for providing plant food and growth.

Of the four provenances, Chimanimani provenance had the highest above and below ground biomass yield but, it had very minimal height increment between 49 and 105 days of seedling growth. Chimanimani provenance had produced the lowest mean seedling height by the time the experiment was terminated. The low mean seedling height could probably be attributed to the death of good performing seedlings before the second and third measurements were done. Solwezi provenance had inferior height and biomass yields although to some extent this was compensated by its larger mean root collar diameter it achieved by 217 days of age.

If heights, diameter and below ground biomass yields are taken as measures of a good performing provenance, then in this case, Mufumbwe provenance proved to be more superior than other provenances. However, methods used in assessing plant productivity vary from scientist to scientist. According to Otieno *et al.* (1991) the best single measure of a plant success is its rate of dry biomass weight increase. On the contrary, Zohar (1991) considered the trees' vitality, size, growth rate and form when selecting best performing trees.

Dry below ground biomass which was more in production than dry above ground biomass indicate that root development as opposed to shoot development is the main activity at least during the first 9 months of *P. angolensis* seedling growth. And also the amount of below ground biomass production might have been more than above ground biomass production because of the effect the die-back phase had on seedlings. Just before assessments were done, all seedlings had shed their leaves. According to Chidumayo (1993) and Piearce (1993) many of the indigenous tree species of the miombo woodland including *P. angolensis* have a habit of annual shoot die-back during the first few seasons of seedling growth. During this period, all the leaf matter dies and drops leading to massive development of the root system, especially the tap root. Therefore, root development seems to take place at the expense of shoot development. From this study, it appears it is better to take below ground development as an indicator of good growth than to rely on above ground biomass. Slow shoot growth among *P. angolensis* seedlings may be to do with their genetic makeup and probably strong influence from the environment under which they were grown. Chidumayo (1993) also observed the slowness of miombo woodland species, including *P. angolensis*, in height growth. The extensive and deep root development of *P. angolensis* imply that it would be difficult to propagate it in the nursery.

In general, below ground biomass production was not satisfactory considering the number of months (10) seedlings were growing in the nursery. Keeping the seedlings for a much longer period and growing them in fertile medium might greatly improve on biomass production especially below ground. An example is given of 17 months old *P. angolensis* seedlings growing in black humic soil under the same conditions in the Faculty of Forestry nursery, University of Stellenbosch (Table 3.1 for cation exchange capacity) which produced an average of 2.78 grams of below ground biomass and 0.73 grams of above ground biomass (personal observation).

From this experiment, it shows that seedling growth results at 217 days could give a good indication of the growth potential of the provenances and as to which seed sources are good or poor. Results also show that selection for the best provenances could be made possible as early as 49 days from time of sowing the seed. Some experimentation would be needed to see how well early results will correlate with more mature results.

The eleven families from Masese provenance also exhibited varied differences in seedling height growth rate and biomass production from the first observation at 38 days to the last observation at 245 days of growing. The best performing families 8 and 2 were from the same location as the worst family 11 in terms of height growth rate. These results indicated that seeds collected from trees that are closely located could also vary in their performance and may not produce similar results even if tried under a similar environment. According to Morgenstern *et al.* (1981) and Hibberd (1991) the variations are expected even if seeds are of the same species but collected across its range although planted on the same site.

As of 38 days, family 7 had no significant difference with family 11 and family 1 in height growth but, by the time seedlings were 95 days, family 7 had grown faster than family 11 and family 1. Therefore, by 95 days, significant differences were observed between family 7 and 11 (Tables 4.20 and 4.21). This ability was also observed in the four provenaces where, Solwezi provenance had initial slow height growth but managed to perform better than Chimanimani provenance by the time seedlings were 105 days old. From these results it seems height increment and seedling establishment rates vary strongly between families, individuals, provenances and that seedling growth rate can start off slowly and later pick up with time. According to Calvert (1986) the variation in growth rates can make accurate prediction of future yields difficult. The results may also imply that seedling performance should not be concluded too early as seedlings of different families vary in their initial rate of development. However, not much time is needed to discover such growth differences as in this experiment, differences were discovered within 95 days. From these results, it seems early utilisation of good performing families and individuals could be possible. Overall, family 11 proved to be a very poor seed source. As for provenances, juvenile-mature correlations need to be studied over longer periods.

Seedling die-back had greatly affected mean seedling heights in many families as of 245 days old example, family 3, 7 and 10. It is suspected the best performing seedlings had died back to ground level or died completely hence affecting seedling mean heights. According to Vermeulen (1990) most seedlings do not recover after going through the die-back phase. This situation would make determination of the best performing family based on height growth difficult and complicated although it may seem easy to measure and has a great visual impact.

In the family trial, there was significant positive correlation ($r = 0.30188$; $P = 0.0001$) between height and number of leaves produced. But it appeared, even if a plant had more leaves, height growth was not influenced. For example, the number of leaves produced was highest in family 8 and lowest in family 2 but the two did not differ significantly in height production.

In as much as fertiliser application was expected to increase seedling growth and their potential to survive, in the family trial almost all seedlings had died after receiving a small dose of 2 grams per plant at four months of growing. However, Donald (1979) highlighted possible draw backs from using inorganic fertilisers to be seedling scorch damage and leaching of nutrients.

On average, the family trial with seeds collected from the same locality showed better height growth than the mean of all provenances (Table 4.1). It would appear a good selection of plus trees was made prior to seed collection. It is also possible that the eleven families could have been from very superior trees to the other four seed sources.

Although in general, no provenance and family had remarkable growth in height, diameter and biomass, there were a few individual seedlings within these provenances and families which exhibited excellent growth. These variations could provide a basis for further improvement programmes.

Variations in rate of seedling growth which were observed in the family and provenance trials were expected with natural trees which have not been exposed to artificial selection. According to Van Wyk (1983) and Hibberd (1991) no two individual trees in a natural stand of trees are alike. Trees are said to vary in size, form, vigour, height growth, crown formation and timber quality. The initial best source of material for selection for tree improvement programmes are therefore, natural forests because of the great natural variations that exist (Eldridge *et al.*, 1994).

The results outlined above indicate the genetic and geographic variation of *P. angolensis* species that could be manipulated for improving seed and timber production. These improvements can bring about potential benefits to the national economies. An example of beneficial results from tree improvement activities was given by Jones *et al.* (1995) who recorded approximately 11.7 kg of black walnuts per tree per year from a grafted plantation of

selected trees. When compared with a plantation of wild trees, only 1.2 kg of nuts per tree per year were produced in the same period in Missouri, Columbia. In the study under review, in all families and provenances studied, there were some particular outstanding individuals (plus trees) which could be selected for establishment of clonal and seedling seed orchards. These seed orchards could bring about economic benefits to the nation by supplying high quantity and quality propagules for sale to the public and for future breeding programmes. Once seed orchards are established, propagules would also be collected cheaply since plus trees will be concentrated in one area. Currently, *P. angolensis* seed collection is expensive partly due to the long distances that are travelled in order to get naturally growing plus trees which are scattered in distribution. Establishment of artificial plantations which could be uniform in growth and mature early for supply of high quantity and quality timber would also be possible.

The information obtained from these family and provenance trials would also assist in determining the best geographic seed source which could be used for future tree improvement, breeding and domestication work if the initial results are maintained to later ages, e.g. for the next 10-15 years. According to Young (1982), Denison and Quaile (1987), Falkenhagen (1990) and Hibberd (1991) the potential for selection and breeding within the right provenance is clearly high and this would increase genetic gain percentages. Zobel and Talbert (1984) reported on losses from using the wrong sources of seed to be big and disastrous. The success of establishment and productivity of afforestation programmes depend on the quality of seed sources that are used.

The information obtained from family and provenance trials may therefore assist in selecting superior parents to be used in the creation of superior genotypes. This exercise could bring about increased yield and high monetary gains.

5.2 Vegetative propagation

P. angolensis is said to be difficult to vegetatively propagate from cuttings (Edwards, 1981, unpublished report). All diameter classes investigated in this experiment easily sprouted regardless of their size though root development was absent. High air temperatures in the glass house might have promoted shoot growth in preference to root initiation. Maile and Nieuwenhuis (1996) made the same observations with *Eucalyptus nitens* growing under

plastic covers. However, cuttings with mid-diameter class 3 - 4.9 cm seemed to be the only size that remained with shoots still alive by the time it was 104 days whereas, the rest of the diameter classes (1 - 1.9 and 2 - 2.9 cm) had all the shoots wilted and dead by that time (Fig. 15). The tendency of shoot death after a few weeks of sprouting is reported to be common in *P. angolensis* cuttings. Kambala (1982, unpublished report), Nkaonja (1982) and Zimmerman (1984) also observed frequent sprouting of poles and truncheons planted in the ground which later died. According to Groome *et al.* (1957) and Zimmerman (1984) *P. angolensis* cuttings are able to sprout and at times even flower if obtained from older parts of the tree although sprouts later die. The tendency of cuttings to sprout and subsequently die was also observed in this experiment. The death of sprouts could have been due to lack of food reserves to sustain the newly formed shoots. The persistence of any shoot and root development depends on the ability of cuttings to obtain water and nutrients. These resources are required in order to sustain shoot and root growth. Initially, cuttings rely on the stored food reserves for any development. Once these stored reserves are exhausted in the cuttings, sprouts die unless there is additional nutrient supply. Use of soil rich in nutrients was proposed by Vermeulen (1990) to raise cuttings if good results are to be obtained.

Poor results with artificial regeneration using *P. angolensis* cuttings could also have been due to lack of early root development to extract water and nutrients. Once shoots are formed, they are expected to start photosynthesising but this can only take place if cuttings are able to extract minerals and water from the growing medium. Water is an essential ingredient in photosynthesis (Mader, 1996). Root development takes place once shoots and cuttings have enough carbohydrates for plant growth. In the absence of roots and sufficient food reserves in cuttings, shoots die as they cannot support themselves. All cuttings that had their sprouts dead or had none developed by the end of the experiment showed no sign of root development. From this experiment, it seems, sprouting is not an indication of root development.

Generally, the number of cuttings which maintained their shoots up to the end of the experiment was quite low (10%). The results indicated that diameter class 3 - 4.9 cm had the capacity to maintain shoots for a much longer period than other diameter classes probably due to their large size and sufficient food reserves. On the other hand, Palgrave (1988) attributed good performance of truncheons to high rising sap in summer.

The number of cuttings which never sprouted at all was highest in mid-diameter class 1 - 1.9 cm (26%) and lowest in mid-diameter class 3 - 4.9 cm (3%) (Fig. 15). Lack of sprouting in thin cuttings could have been due to their failure to support shoot development due to insufficient food reserves. According to Trapnell, (1959) young twigs usually fail to shoot and root because of not having sufficient food reserves.

The growth hormone used was expected to induce root development. But from the results obtained, it seems the growth hormone had no major influence on rooting of cuttings. Method of growth hormone application and its concentration might have affected the shoot and root formation. A combination of rooting hormones at low concentrations may give an improved result (Maile and Nieuwenhuis, 1996) and according to Donald (1987) increasing the concentration of the growth hormone may also improve the speed of rooting by cuttings. The rooting medium (sand) used was convenient for easy uprooting of cuttings and easy growth of anticipated roots but, might have lacked nutrients and the watering regime was probably insufficient to support sprouts. Farnsworth and Gaum (1995) reported on the possibility of the porosity of sand not able to retain sufficient amount of moisture to stimulate production of *Ocotea bullata* roots. Fluctuations in temperatures of the growing medium during day and night could have also affected the results of the experiment.

The information obtained from this trial may be of help in many ways. For example, micropropagation techniques such as tissue culture can utilise the individuals or diameter classes that performed better in early shoot production and those that maintained their shoots for a long period such as diameter class 3 - 4.9 cm. These individuals can be used to provide superior propagules for massive plant production and future research work. Many researchers have proved that use of superior propagules can bring about potential monetary gains in a short time. An example is given by the Mondi Forest clonal programme for sub-tropical *Eucalyptus,* South Africa, which took only three years to develop a programme to supply high yielding vegetatively propagated plants. By 1987, the annual capacity of the two nurseries was 7.2 million (Denison and Quaile, 1987) and later, production increased to more than 10 million clonal plants annually (Wright and Baylis, 1993). Diameter class 3 - 4.9 cm can in addition form a basis for further research work on the rooting ability of *P. angolensis* cuttings. Manipulation of the observed sprouting ability variations can bring about better tree

improvement and hence potential benefits from *P. angolensis*. Improved tree growth, timber quality and timber production are some of the benefits that could be expected from such work.

6. Conclusions and recommendations

6.1 Conclusions

Despite the economic importance of *P. angolensis*, little or no research on vegetative propagation, family and provenance trials have been conducted yet, these are necessary prior to any tree breeding, tree improvement and domestication work on the species. The need to produce high quantity and high quality timber from *P. angolensis* has been identified earlier on. It is through use of knowledge obtained from such trials as mentioned above that these achievements can be met. The full economic potential of *P. angolensis* has not yet been realised due to lack of information on its silviculture and tree improvement.

Although soil sterilisation is common practice in forestry nurseries especially before introducing the required mycorrhizal fungi to the growing medium, from the results of the provenance trials, it seems soil sterilisation should be used with caution when dealing with *P. angolensis.* In this study, soil sterilisation had less effect than soil inoculation on seedling height growth meaning *P. angolensis* seedlings can still perform better without necessarily incurring any extra costs in sterilising the soil.

Soil inoculation is an important practice as long as the right kind of inoculum is used in the proper growing medium. Soil inoculation has been found to improve growth rates, e.g. height, diameter and biomass both below and above ground.

Family and provenance trials confirmed that variations do exist among families collected within the same vicinity and among provenances from a wide geographic range. Utilisation of these variations could be of economic importance. Seed and clonal orchards are some of the beneficial products from using family and provenance variations. Genetic variation is said to be a corner stone of tree breeding and without these variations, there can be no basis for tree breeding and tree improvement programmes (Cossalter, 1988).

Use of wrong fertiliser types and doses and probably wrong timing can be disastrous as seen from the family trial results. Care is needed when using inorganic fertilisers.

From the vegetative propagation experiment it is concluded that *P. angolensis* cuttings can easily sprout regardless of their diameter size. However, maintenance of these sprouts seems to depend on the amount of food reserves available both in the cuttings and the growing medium. Larger cuttings (3 - 4.9 cm diameter) seem to maintain shoots for a much longer period than thinner cuttings (< 2.9 cm diameter). The large diameter class (3 - 4.9 cm) could be used for further research work to improve on the species' sprouting and rooting ability. Use of vegetative propagation can enhance the potential of *P. angolensis* for large scale artificial planting. Similar results as those obtained by Mondi Forest Clonal Programme for sub-tropical *Eucalyptus* could also be possible and obtained with *P. angolensis* through use of vegetative propagation.

6.2 Recommendations

6.2.1 *Provenance and family trials*

The following recommendations are made:

(i) Further research on which species of mycorrhizal fungi are symbiotic with seedlings of *P. angolensis* is required.
(ii) Further investigations on which mycorrhizal fungi are recolonisers of sterilised soil.
(iii) Further research on why sterilised and inoculated soils did not perform better than not sterilised but inoculated soils need to be done.
(iv) A detailed study on what type and level of fertiliser should be used in raising *P. angolensis* seedlings is required.
(v) Further investigations on time of year when seedlings are to be fertilised need to be conducted.
(vi) There is a need to carry out studies on the best pot sizes to be used and how long the seedlings should be kept in the nursery before planting them out in the field.
(vii) More extensive family and provenance trials within the SADC region need to be conducted. This will enable identification of good seed sources in the region. These seed sources will supply the region with the required high quality propagules.
(viii) A detailed research on how yearly die-back of *P. angolensis* comes about and how it can be avoided or shortened need to be done. If the die-back period could be eliminated or shortened *P. angolensis* might take a shorter period to mature than is the case.

6.2.2 *Vegetative propagation trial*

A detailed research on vegetative propagation is required to follow-up on the reported findings by:

(i) Studying the best type of growth hormone and optimum rates of application of the growth hormone.
(ii) Carrying out investigations on why shoots die shortly after sprouting and how best these shoots can be maintained.
(iii) Investigating the best methods of rooting *P. angolensis* cuttings.

(iv) Determining best diameter size to be used in the vegetative propagation programmes.

(v) Researching on the effect of temperature, water and light on the rooting and sprouting ability of *P. angolensis.*

(vi) Studying the effect of age and freshness of cuttings on rooting and shooting ability.

(vii) Identifying superior genotypes to supply parent material to be used in future tree improvement programmes.

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Appendices

1. ANOVA tables for provenance trial

Table 1.1. ANOVA for seed germination using square root transformed data.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	8.67490987	0.25514441	3.30	0.0001
Error	271	20.94477520	0.07728699		
Corrected total	3.05	29.61968507			
	R-Square	C.V.	Root MSE		Germinated Mean
	0.292877	17.02032	0.2780054		1.6333738

Source	DF	Anova SS	Mean square	F Value	Pr > F
Replication	19	2.71629060	0.14296266	1.85	0.0181
Provenance	3	4.87852847	1.62617616	21.04	0.0001
Sterilization	1	0.29613955	0.29613955	3.83	0.0513
Inoculation	1	0.00345514	0.00345514	0.04	0.8327
Prov*Sterilizatio	3	0.34904006	0.11634669	1.51	0.2134
Prov*Inoculation	3	0.19194027	0.06398009	0.83	0.4795
Sterile*inoculation	1	0.14424152	0.14424152	1.87	0.1730
Prov*sterile*inocula	3	0.09527425	0.03175808	0.41	0.7453

Table 1.2. ANOVA for height growth at 49 days.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	310.5660901	9.13429677	4.92	0.0001
Error	1092	2029.362606	1.85839066		
Corrected Total	1126	2339.928696			
	R-Square	C.V.	Root MSE	HEIGHT Mean	
	0.132725	34.86572	1.363228	3.9099379	

Source	DF	Type 1 SS	Mean square	F Value	Pr >F
Replication	19	140.84172184	7.4127222	3.99	0.0001
Provenance	3	54.29534293	18.09844764	9.74	0.0001
Sterilization	1	24.53358056	24.53358056	13.20	0.0003
Inoculation	1	65.29356603	65.29356603	35.13	0.0001
Prov*Sterilization	3	1.83458676	0.61152892	0.33	0.8043
Prov*inoculation	3	12.32777467	4.10925822	2.21	0.0852
Sterili*inoculation	1	4.82150616	4.82150616	2.59	0.1075
Prov*Sterili*inocu	3	6.6180111	2.2060037	1.19	0.3134

Table 1.3. ANOVA for height growth at 105 days.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	414.7317042	12.1979913	7.19	0.0001
Error	1074	1821.767592	1.69624543		
Corrected Total	1108	2236.499297			
	R-Square	C.V.	Root MSE	HEIGHT mean	
	0.185438	30.86638	1.3023999	4.219477	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	19	173.90704643	9.15300244	5.40	0.0001
Provenance	3	105.05087550	35.01695850	20.64	0.0001
Sterilization	1	21.09741212	21.09741212	12.44	0.0004
Inoculation	1	96.47332701	96.47332701	56.87	0.0001
Prov*Sterilization	3	3.17257964	1.05752655	0.62	0.5999
Prov*inoculation	3	6.97839648	2.32613216	1.37	0.2500
Sterili*inoculation	1	2.27271636	2.27271636	1.34	0.2473
Prov*Sterili*inocu	3	5.77935067	1.92645022	1.14	0.3335

Table 1.4. ANOVA for height growth at 217 days.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	289.06782123	8.50199474	5.16	0.0001
Error	912	1501.27166662	1.64613121		
Corrected Total	946	1790.33948786			
	R-Square	C.V.	Root MSE	HEIGHT mean	
	0.161460	28.37664	1.2830165	4.5213833	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	19	97.12385433	5.11178181	3.11	0.0001
Provenance	3	84.13094307	28.04364769	17.04	0.0001
Sterilization	1	16.48705104	16.48705104	10.02	0.0016
Inoculation	1	69.24672600	69.24672600	42.07	0.0001
Prov*Sterilization	3	2.65054098	0.88351366	0.54	0.6572
Prov*inoculation	3	9.54601320	3.18200440	1.93	0.1226
Sterili*inoculation	1	1.48112485	1.48112485	0.90	0.3431
Prov*Sterili*inocu	3	8.40156776	2.80052259	1.70	0.1652

Table 1.5. ANOVA for root collar diameter growth at 217 days.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	48.49949116	1.42645562	4.07	0.0001
Error	881	309.07512762	0.35082307		
Corrected Total	915	357.57461878			
	R-Square	C.V.	Root MSE	DIAMETER mean	
	0.135635	33.33475	0.5923032	1.7768341	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	19	11.80818458	0.62148340	1.77	0.0219
Provenance	3	18.29549379	6.09849793	17.38	0.0001
Sterilization	1	6.30073663	6.30073663	17.96	0.0001
Inoculation	1	6.93447816	6.93447816	19.77	0.0001
Prov*Sterilization	3	0.29167753	0.09722584	0.28	0.8419
Prov*inoculation	3	3.75555716	1.25185239	3.57	0.0138
Sterili*inoculation	1	0.36340212	0.36340212	1.04	0.3091
Prov*Sterili*inocu	3	0.74996118	0.24998706	0.71	0.5446

Table 1.6. ANOVA for above ground biomass production at 217 days of seedling growth.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	2.44617885	0.07194644	5.92	0.0001
Error	269	3.26662082	0.01214357		
Corrected Total	303	5.71279967			
	R-Square	C.V.	Root MSE	BIOMASS mean	
	0.428193	46.88615	0.1101979	0.2350329	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	19	0.45870614	0.02414243	1.99	0.0093
Provenance	3	1.06131324	0.35377108	29.13	0.0001
Sterilization	1	0.21700563	0.21700563	17.87	0.0001
Inoculation	1	0.47574727	0.47574727	39.18	0.0001
Prov*Sterilization	3	0.03218082	0.01072694	0.88	0.4502
Prov*inoculation	3	0.13032501	0.04344167	3.58	0.0145
Sterili*inoculation	1	0.02932964	0.02932964	2.42	0.1213
Prov*Sterili*inocu	3	0.04157110	0.01385703	1.14	0.3329

Table 1.7. ANOVA for below ground biomass production at 217 days of seedling growth.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	23.97903387	0.70526570	3.18	0.0001
Error	278	61.57154377	0.22148037		
Corrected Total	312	85.55057764			
	R-Square	C.V.	Root MSE	BIOMASS mean	
	0.280291	66.59875	0.4706170	0.7066454	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	19	6.44690268	0.33931067	1.53	0.0740
Provenance	3	6.63851519	2.21283840	9.99	0.0001
Sterilization	1	0.05263425	0.05263425	0.24	0.6263
Inoculation	1	7.48191424	7.48191424	33.78	0.0001
Prov*Sterilization	3	0.53327923	0.17775974	0.80	0.4933
Prov*inoculation	3	2.20067679	0.73355893	3.31	0.0205
Sterili*inoculation	1	0.00000800	0.0000080	0.00	0.9952
Prov*Sterili*inocu	3	0.62510349	0.20836783	0.94	0.4213

Table 1.8. ANOVA for leaf count at 49 days using square root transformed data.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	19.05977768	0.5605817	7.55	0.0001
Error	1087	80.70615665	0.07424669		
Corrected Total	1121	99.76593433			
	R-Square	C.V.	Root MSE	LEAF mean	
	0.191045	8.982038	0.2724825	3.0336375	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	19	1.98336494	0.10438763	1.41	0.1144
Provenance	3	13.34929438	4.44976479	59.93	0.0001
Sterilization	1	0.12601012	0.12601012	1.70	0.1929
Inoculation	1	2.16497725	2.16497725	29.16	0.0001
Prov*Sterilization	3	0.56792116	0.18930705	2.55	0.0544
Prov*inoculation	3	0.22601856	0.07533952	1.01	0.3853
Sterili*inoculation	1	0.02179531	0.02179531	0.29	0.5881
Prov*Sterili*inocu	3	0.62039596	0.20679865	2.79	0.0397

Table 1.9. ANOVA for leaf count at 105 days using square root Transformed data.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	34	25.95425796	0.76336053	14.94	0.0001
Error	1074	54.88528585	0.05110362		
Corrected Total	1108	80.83954381			
	R-Square	C.V.	Root MSE	LEAF mean	
	0.321059	6.857858	0.2260611	3.2963806	

Source	DF	Type 1 SS	Mean square	F Value	Pr >F
Replication	19	1.11413000	0.05863842	1.15	0.2967
Provenance	3	22.02760817	7.34253606	143.68	0.0001
Sterilization	1	0.19334369	0.19334369	3.78	0.0520
Inoculation	1	1.73456964	1.73456964	33.94	0.0001
Prov*Sterilization	3	0.14879177	0.04959726	0.97	0.4059
Prov*inoculation	3	0.15281937	0.05093979	1.00	0.3935
Sterili*inoculation	1	0.03571954	0.03571954	0.70	0.4033
Prov*Sterili*inocu	3	0.54727579	0.18242526	3.57	0.0137

Table 1.10. Correlation between seed mass and seed germination of *P. angolensis.*

Variable	N	Mean	Standard deviation	Minimum	Maximum
Germination	11	73.54545	11.15673	52	91
Mass	11	18.74	2.82751	14	22.58

Pearson Correlation Coefficients / Prob > :R: under Ho: Rho=0 / N = 11

	Germination	Mass
Germination	1	-0.14091
	0	0.6794
Mass	-0.14091	1
	0.6794	0

2. ANOVA tables for family trial

Table 2.1. ANOVA for number of germinated seed using square root transformed data

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	5.65483307	0.29762279	4.44	0.0001
Error	90	6.02853172	0.06698369		
Corrected total	109	11.68336479			
	R-Square	C.V.	Root MSE	Germinated Mean	
	0.484007	9.613144	0.2588121	2.6922728	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	9	1.13228284	0.12580920	1.88	0.0658
Family	10	4.52255023	0.45225502	6.75	0.0001

Table 2.2. ANOVA for height growth at 38 days

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	193.117444	10.164076	10.57	0.0001
Error	634	609.9162716	0.96201305		
Corrected Total	653	803.0337156			
	R-Square	C.V.	Root MSE	HEIGHT mean	
	0.240485	21.67454	0.9808226	4.5252294	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	9	33.92447412	3.76938601	3.92	0.0001
Family	10	159.1929699	15.91929698	16.55	0.0001

Table 2.3. ANOVA for height growth at 95 days.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	212.4731728	11.1827986	11.85	0.0001
Error	635	599.2789799	0.94374643		
Corrected Total	654	811.7521527			
	R-Square	C.V.	Root MSE	HEIGHT mean	
	0.261746	20.3307	0.9714661	4.7783206	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Rep	9	44.35213905	4.92801545	5.22	0.0001
Family	10	168.1210337	16.81210337	17.81	0.0001

Table 2.4. ANOVA for height growth at 245 days of seedling growth.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	56.18340967	2.95702156	3.36	0.0001
Error	245	215.37115637	0.87906594		
Corrected Total	264	217.55456604			
	R-Square	C.V.	Root MSE	HEIGHT mean	
	0.206895	19.92942	0.9375852	4.704523	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Rep	9	9.05983604	1.00664845	5.22	0.335
Family	10	47.12357363	4.71235736	17.81	0.001

Table 2.5. ANOVA for diameter growth of *P. angolensis* seedlings at 245 days old.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	5.45998761	0.28736777	1.99	0.004
Error	244	35.17324838	0.14415266		
Corrected Total	263	40.63323598			
	R-Square	C.V.	Root MSE	DIAMETER mean	
	0.134372	26.19334	0.3796744	1.449506	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Rep	9	2.13756742	0.23750749	1.65	0.105
Family	10	3.32242019	0.33224202	2.30	0.013

Table 2.6. ANOVA for leaf count at 38 days using square root transformed data.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	2.3066117	0.12140062	4.45	0.0001
Error	634	17.29941235	0.02728614		
Corrected Total	653	19.60602405			
	R-Square	C.V.	Root MSE	HEIGHT mean	
	0.117648	5.299879	0.1651852	3.1167723	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	9	0.51675647	0.05741739	2.10	0.0273
Family	10	1.78985523	0.17898552	6.56	0.0001

Table 2.7. ANOVA for above ground biomass growth at 245 days of *P. angolensis* seedling growth.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	0.07764846	0.00408676	1.82	0.0241
Error	175	0.39382641	0.00225044		
Corrected Total	194	0.47147487			
	R-Square	C.V.	Root MSE	Biomass mean	
	0.164693	55.79348	0.0474388	0.08502	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	9	0.04338479	0.00482053	2.14	0.020283
Family	10	0.03426367	0.00342637	1.52	0.1347

Table 2.8. ANOVA for below ground biomass growth at 245 days of *P. angolensis* seedling growth.

Source	DF	Sum of Squares	Mean Square	F Value	P >F
Model	19	1.90446897	0.10023521	2.51	0.0015
Error	176	7.31891623	0.04158475		
Corrected Total	195	9.22338520			
	R-Square	C.V.	Root MSE	Biomass mean	
	0.206483	42.41641	0.2039234	0.48076	

Source	DF	Type 1 SS	Mean square	F Value	Pr > F
Replication	9	1.28218246	0.14246472	3.43	0.0007
Family	10	0.62228652	0.06222865	1.50	0.1440

Table 2.9. Correlation between seedling height and below and above ground biomass of *P. angolensis*.

Variable	N	Mean	Standard deviation	Minimum	Maximum
Height	265	4.71 (cm)	1.01	2.5	9.0
Biomass (above)	195	0.09 (gm)	0.05	0.01	0.36
Biomass (below)	196	0.48 (gm)	0.22	0.08	1.17

Pearson Correlation Coefficients / Prob > :R: under Ho: Rho=0 / number of observations

	Biomass (above)	Biomass (below)
Height	0.18721	-0.06242
P-Value	0.0099	0.3922